HS 2022

Structural Design

D-BAUG - MIBS

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Teaching Team

Introduction

Week 1	22.9.	Global Equilibrium
Week 2	29.9.	
Week 3	06.10.	
Week 4	13.10.	Local Equilibrium
Week 5	20.10.	
Week 6	27.10.	
Week 7	03.11.	Design Exercise (midterm)
Week 8	**10.11.**	
Week 9	17.11.	Material and construction
Week 10	24.11.	
Week 11	01.12.	Design Exercise (final)
Week 12	08.12.	
Week 13	15.12.	
Week 14	**22.12.**	

Course overview

		Lecture	Exercise session / Task	Submission (Friday 23:59)
Week 1	22.9.	Introduction		
Week 2	29.9.		Basics of graphic statics	
Week 3	06.10.		*Task 0*	
Week 4	13.10.	Theory of Plasticity		Submission of Task 0
Week 5	20.10.		Strut-and-tie models	
Week 6	27.10.		*Design exercise (Task 1)*	
Week 7	03.11.		*Design exercise (Task 1)*	
Week 8	**10.11.**		**Midterm review**	Submission of Task 1
Week 9	17.11.	Stress fields		
Week 10	24.11.		From STM to stress fields	
Week 11	01.12.			
Week 12	08.12.		*Design exercise (Task 2)*	
Week 13	15.12.			Submission of Task 2
Week 14	**22.12.**		**Final review**	

Course overview

		Lecture	Exercise session / Task	Submission (Friday 23:59)
Week 1	22.9.	Introduction		
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Week 5	20.10.		Strut-and-tie models	
Week 6	27.10.		*Design exercise (Task 1)*	
Week 7	03.11.		*Design exercise (Task 1)*	
Week 8	**10.11.**		**Midterm review**	Submission of Task 1
Week 9	17.11.	Stress fields		
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Week 11	01.12.			
Week 12	08.12.		*Design exercise (Task 2)*	
Week 13	15.12.			Submission of Task 2
Week 14	**22.12.**		**Final review**	

Course overview

Theory of Plasticity

Methods bases on plastic theory have been developed to determine the collapse load of structures at their **ultimate limit state**. They comprise the static solution, based on the lower bound theorem, and the dual kinematic solution, based on the upper bound theorem. When the two plastic solutions coincide, the complete solution is achieved.

Condition	Static solution	Complete solution	Kinematic solution
Equilibrium	Ok	Ok	Ok
Yield conditions	Ok	Ok	?
Mechanism	?	Ok	Ok
Result	Lower bound $[Q_S] \leq [Q_R]$	Collapse load $[Q_R]$	Upper bound $[Q_K] \geq [Q_R]$
Method	Static method	-	Mechanism method

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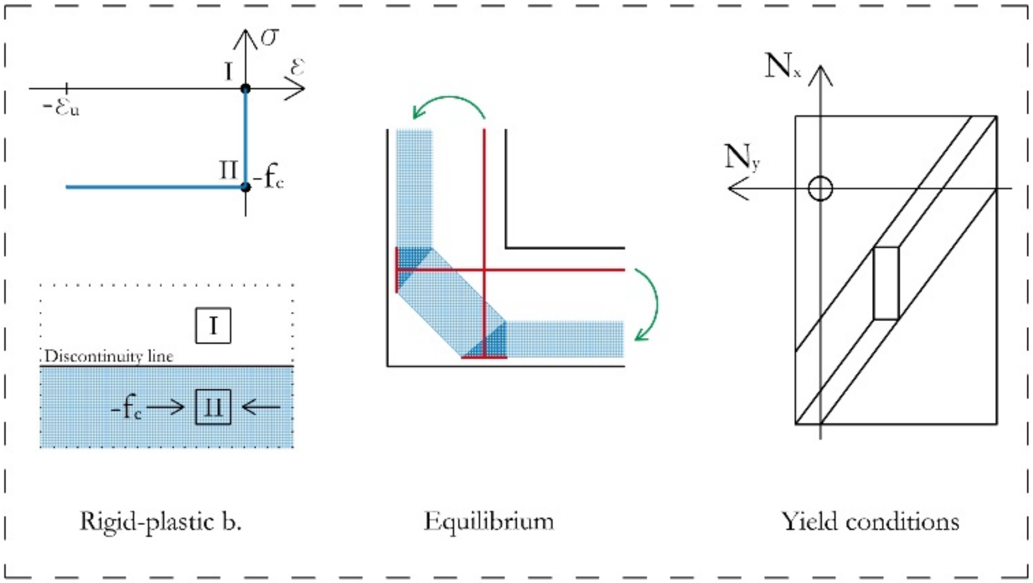
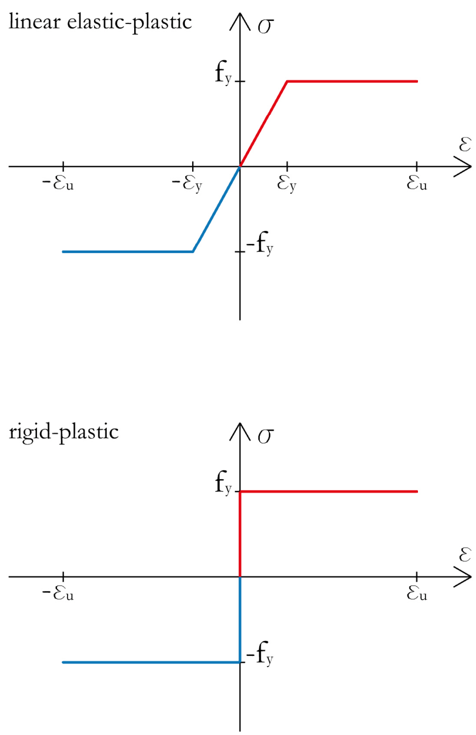
Mechanism	?	Ok	Ok
Result	Lower bound	Collapse load	Upper bound
	$[Q_S] \leq [Q_R]$	$[Q_R]$	$[Q_K] \geq [Q_R]$
Method	Static method	-	Mechanism method

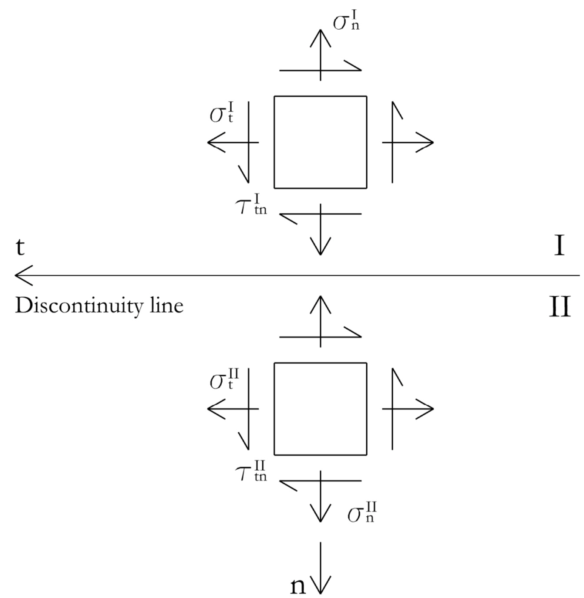
For a lower bound solution to be valid, **three fundamental conditions** must be fulfilled: a rigid plastic behaviour, an admissible state of equilibrium, and compliance with the yield conditions. If these three requirements are met, the lower bound theorem is valid, without further considerations.



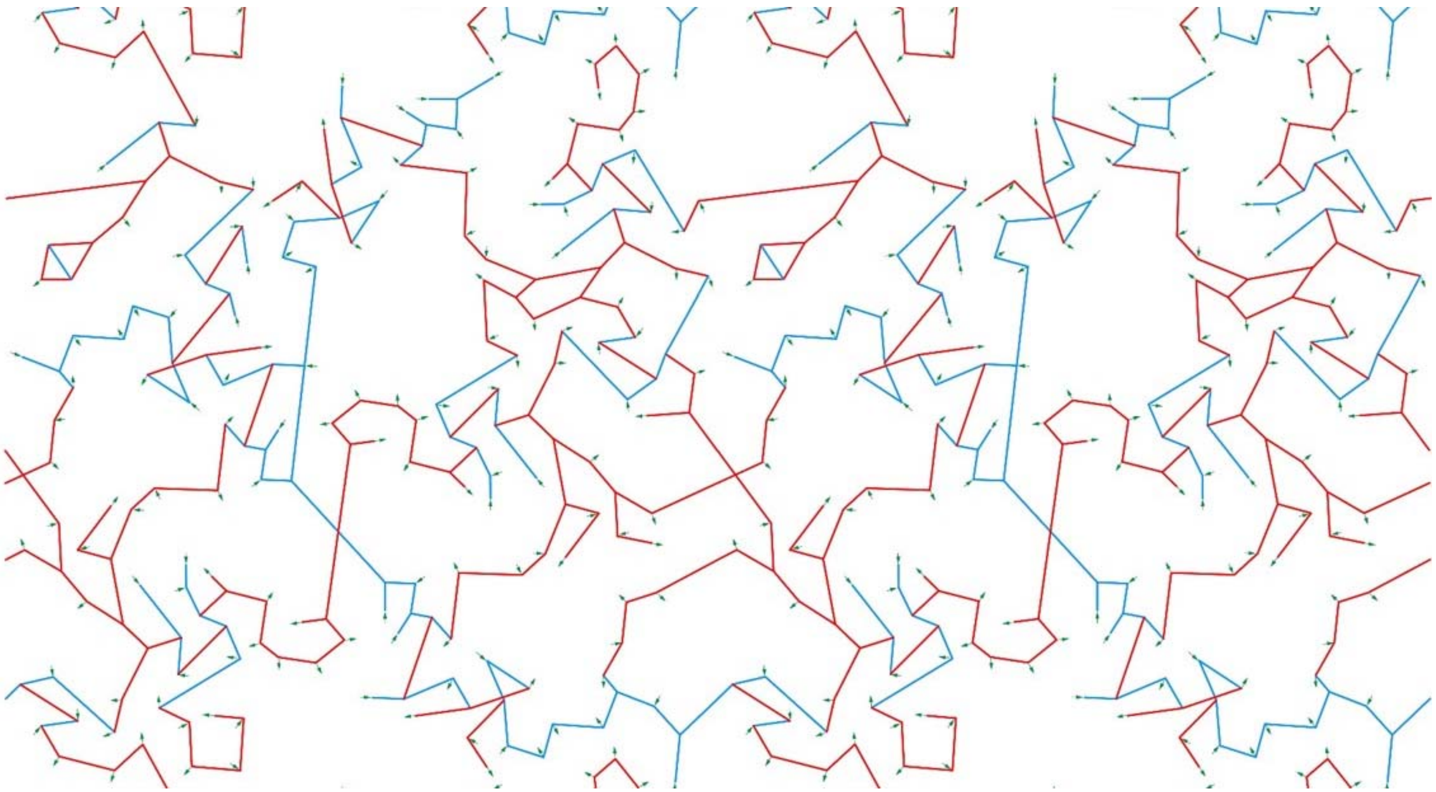
Theoretical model

In a **rigid-plastic behaviour**, the plastic strain is considerably larger than the yield strain, so the latter can be neglected. In this case, no deformations occur until the yielding point is reached and the plastic collapse takes place. Furthermore, the assumption of a rigid-plastic behaviour allows the presence of static discontinuities, which facilitate the development of the equilibrium state.

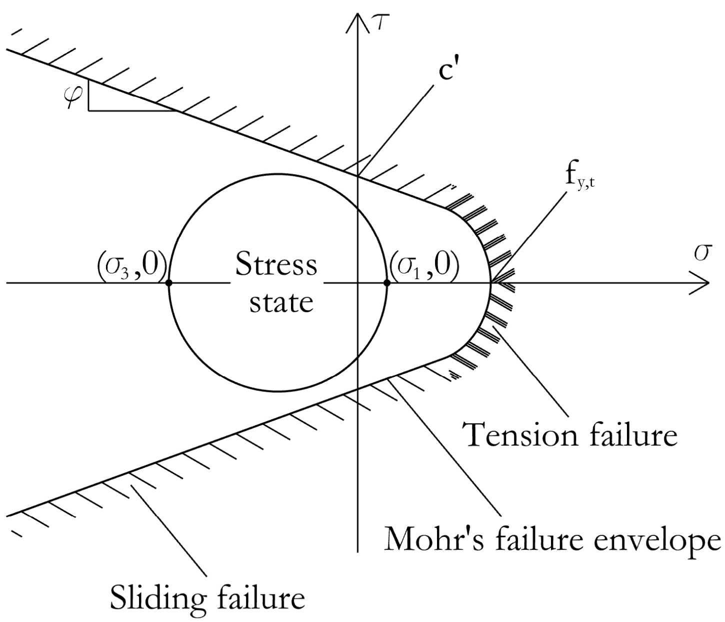




Given external forces and a geometric boundary, the designer is free to define the path of the internal forces by means of stress fields and the corresponding strut-and-ties models. The resulting internal stress state must be in static equilibrium, meaning that the resultant force at each node of the strut-and-tie model is null. If also the boundary conditions are respected, an **admissible state of equilibrium** is achieved.



The **yield conditions** describe the structural limits of a system. At first, the single failure modes are identified and defined. The yield conditions are composed of the combination of the single failure modes and they must not be violated at any point. Once defined, for any stress, it is possible to establish if and how system failure occurs.



Strass state:

σ_i Principal stress

Failure parameters:

c' Cohesion

φ Friction

$f_{y,t}$ Max. tension stress

Failures:

Sliding $|\tau| = c' - \tan(\varphi) \cdot \sigma$

Tension $\sigma = f_{y,t}$

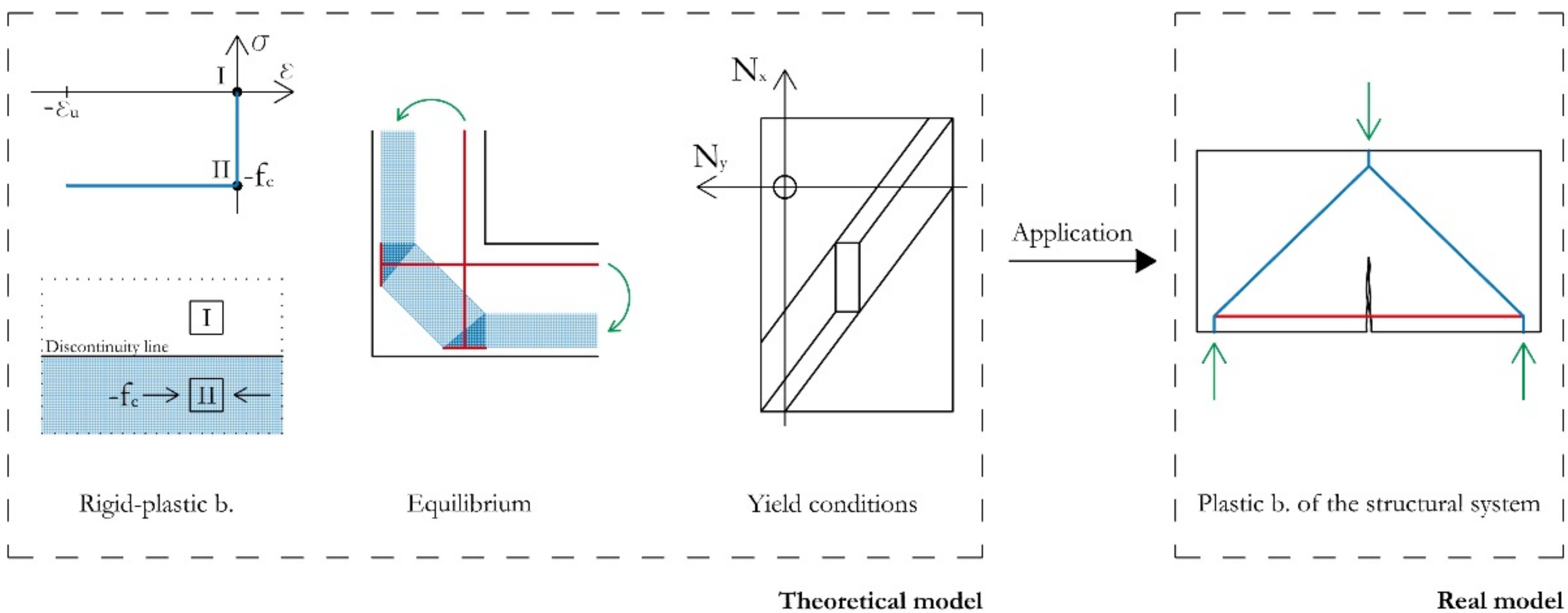
Special cases:

Coulomb No tension failure

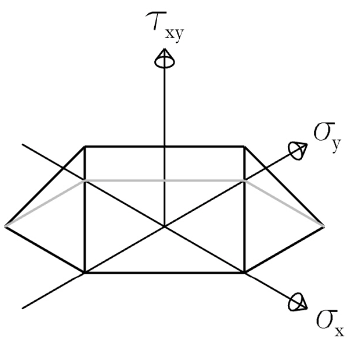
Tresca No tension failure, $\varphi = 0$

Modified Mohr-Coulomb Tension failure (vertical line)

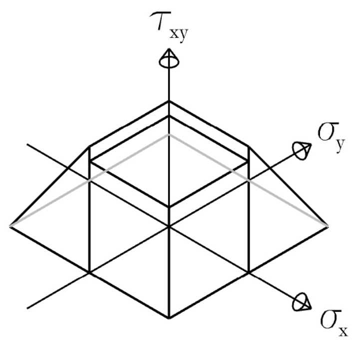
The plastic theory assumes a rigid-plastic behaviour of the material. In civil engineering, this assumption does not necessarily imply the presence of a rigid-plastic material, but rather that the **overall behaviour of the structural system** can be assumed to be rigid-plastic. In particular, the structural system must guarantee the necessary deformation capacity, which allows the plastic redistribution of the internal forces according to the predefined plastic model.



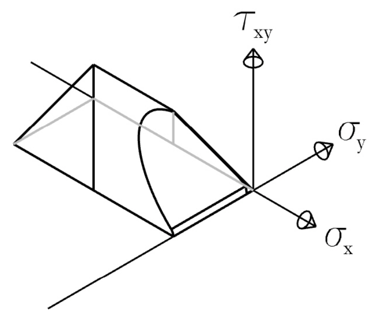
Of the three fundamental conditions imposed by the limit analysis, the derivation of yielding conditions requires a real deep understanding of the mechanical behaviour of the material, and in particular the **different failure modes**. In order to obtain the completed yield condition of a material, each failure mode must be identified and described.



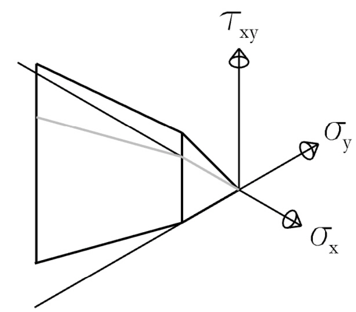
Steel (f_y)



Reinforced concrete (f_y, f_c)



Masonry (f_{m1}, f_{m2}, c', φ)



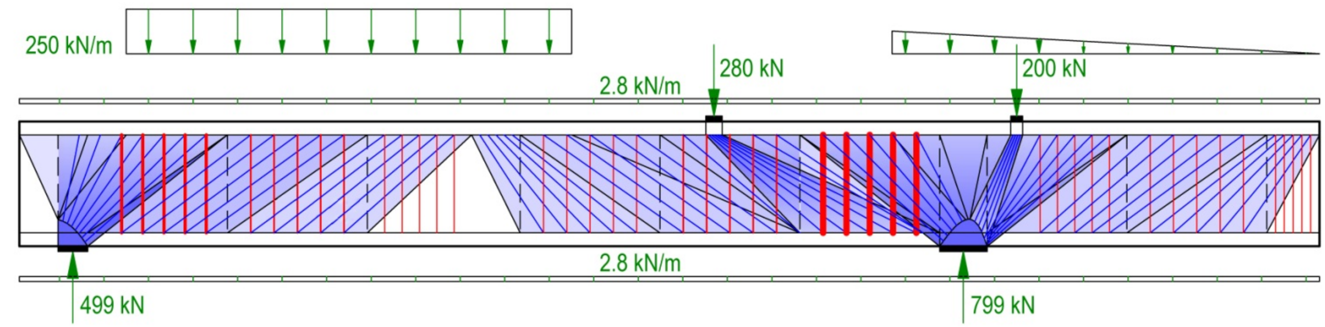
Soil (c', φ)

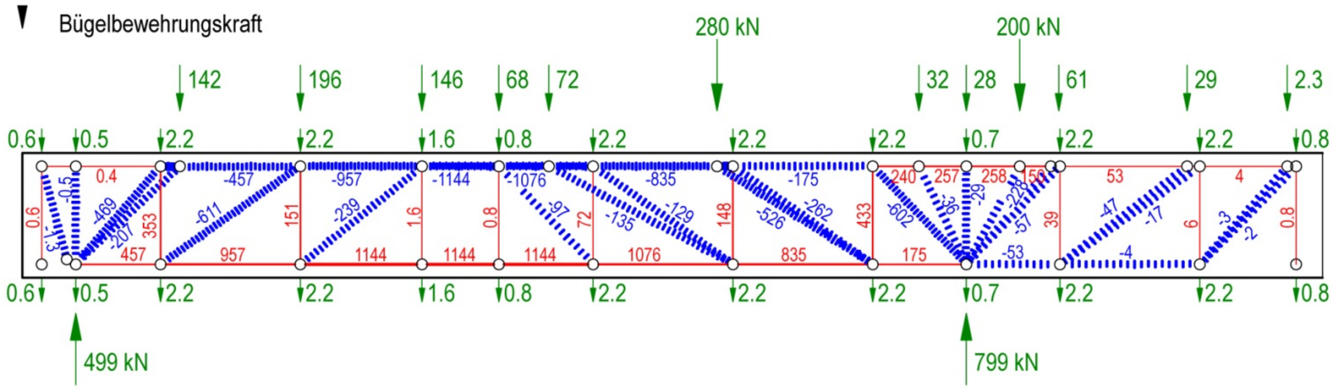
Condition	Static solution	Complete solution	Kinematic solution
Equilibrium	Ok	Ok	Ok
Yield conditions	Ok	Ok	?
Mechanism	?	Ok	Ok
Result	Lower bound $[Q_S] \leq [Q_R]$	Collapse load $[Q_R]$	Upper bound $[Q_K] \geq [Q_R]$
Method	Static method	-	Mechanism method

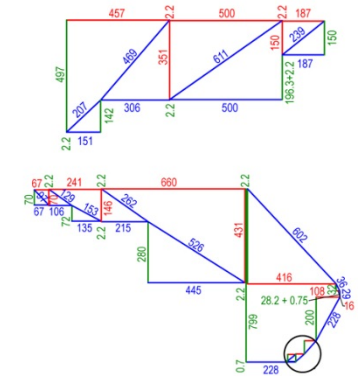
Equilibrium based Design

« In a plastic design a stress field is chosen such that the **equilibrium conditions** and the **statical boundary conditions** are fulfilled.
The dimensions of cross-section and the reinforcement have to be proportioned such that the **resistances** are everywhere greater than or equal to the corresponding internal forces. »

Source: Aurelio Muttoni, Joseph Schwartz, Bruno Thürlimann, Design of concrete structures with stress fields, 1996







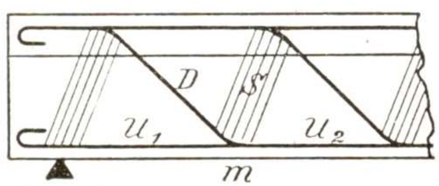
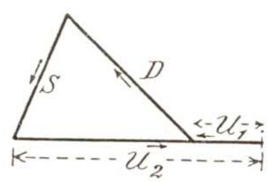


Abb. 570. Fachwerksträger mit rhombischen Feldern.



Kräfteplan für Knotenpunkt *m*.

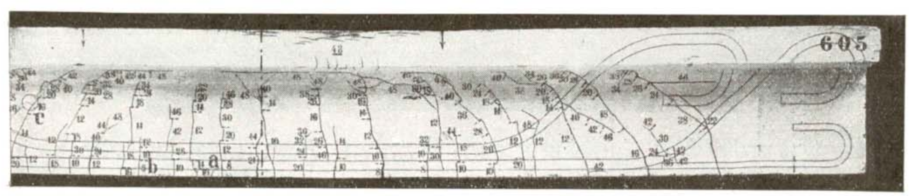
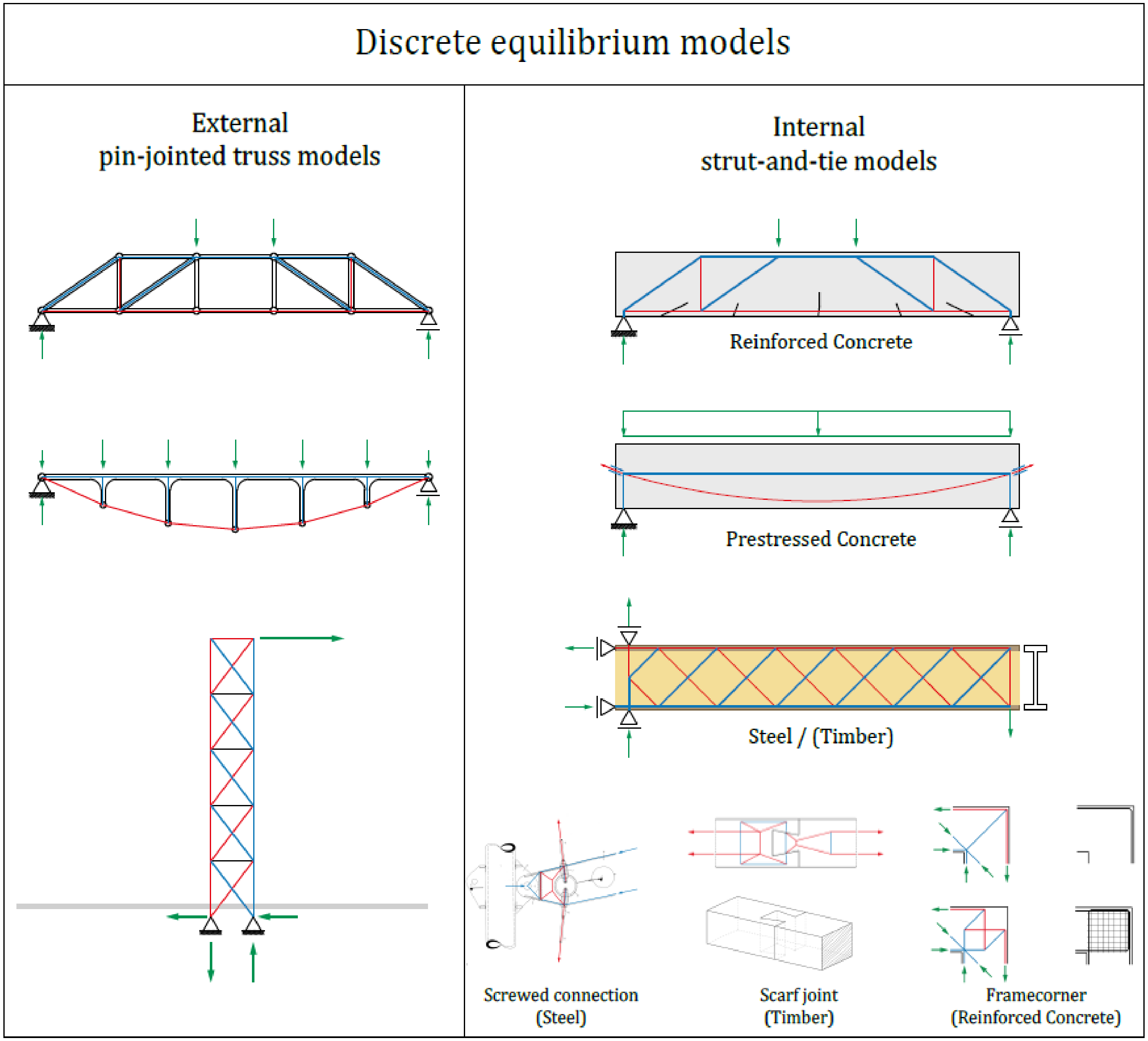
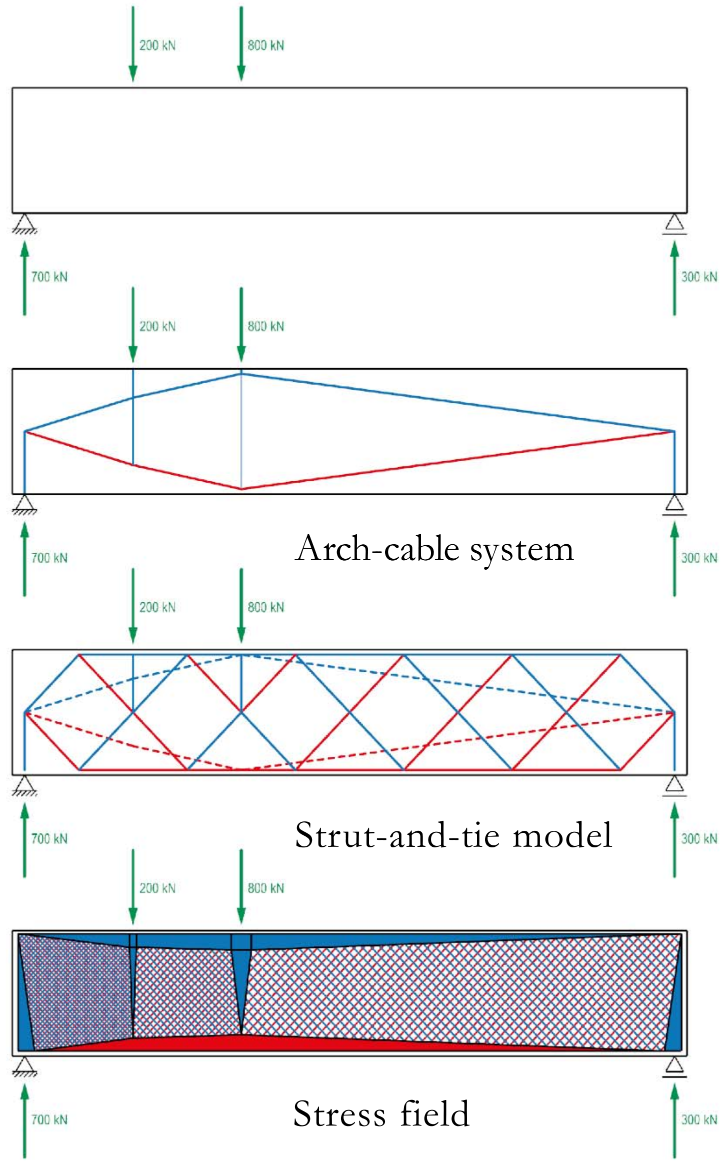


Abb. 571. Gruppe VII. Balken 605 der Reihe 47; $P_m = 48$ t.

Source: Aurelio Muttoni, Joseph Schwartz, Bruno Thürlimann, Design of concrete structures with stress fields, 1996

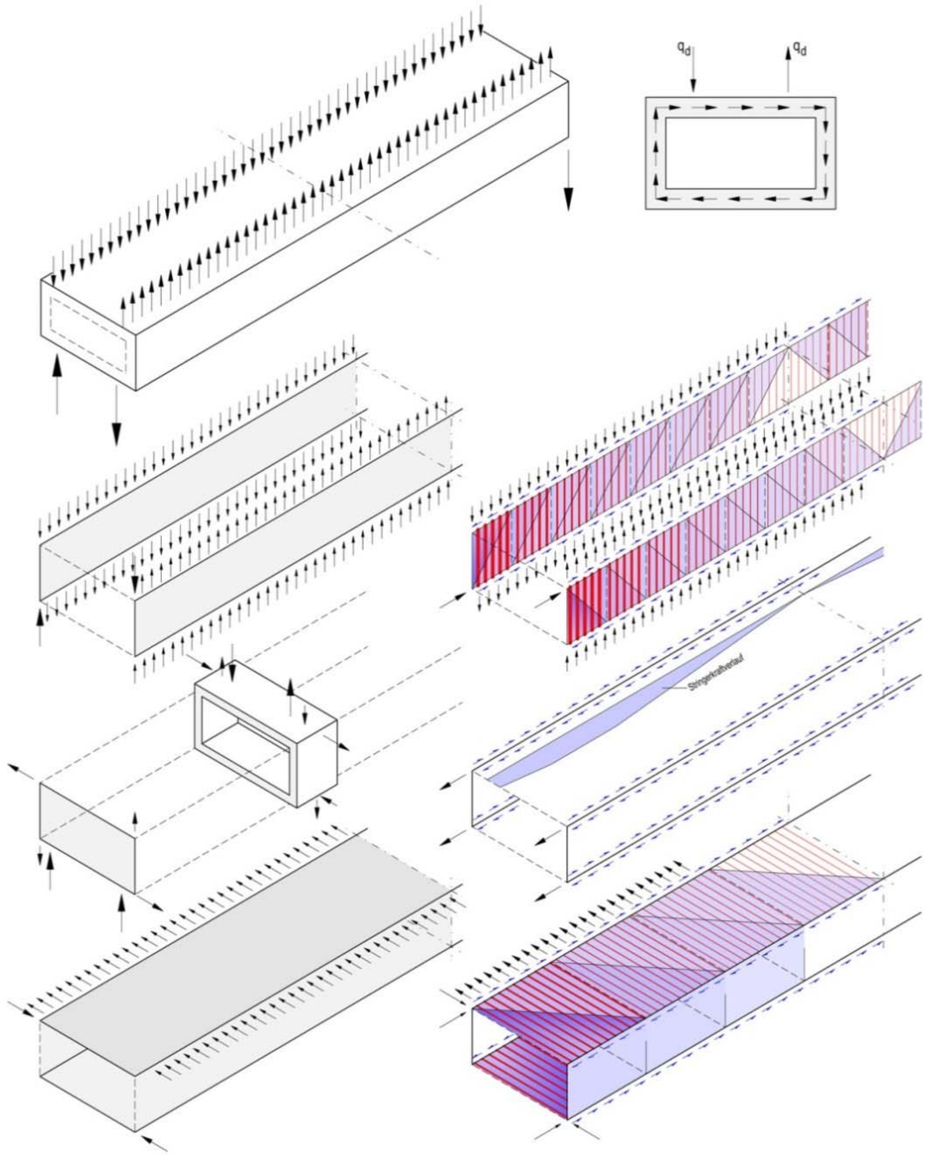

Discrete equilibrium models
External
pin-jointed truss models
Internal
strut-and-tie models
Reinforced Concrete
Prestressed Concrete
Steel / (Timber)
Screwed connection
(Steel)
Scarf joint
(Timber)
Framecorner
(Reinforced Concrete)



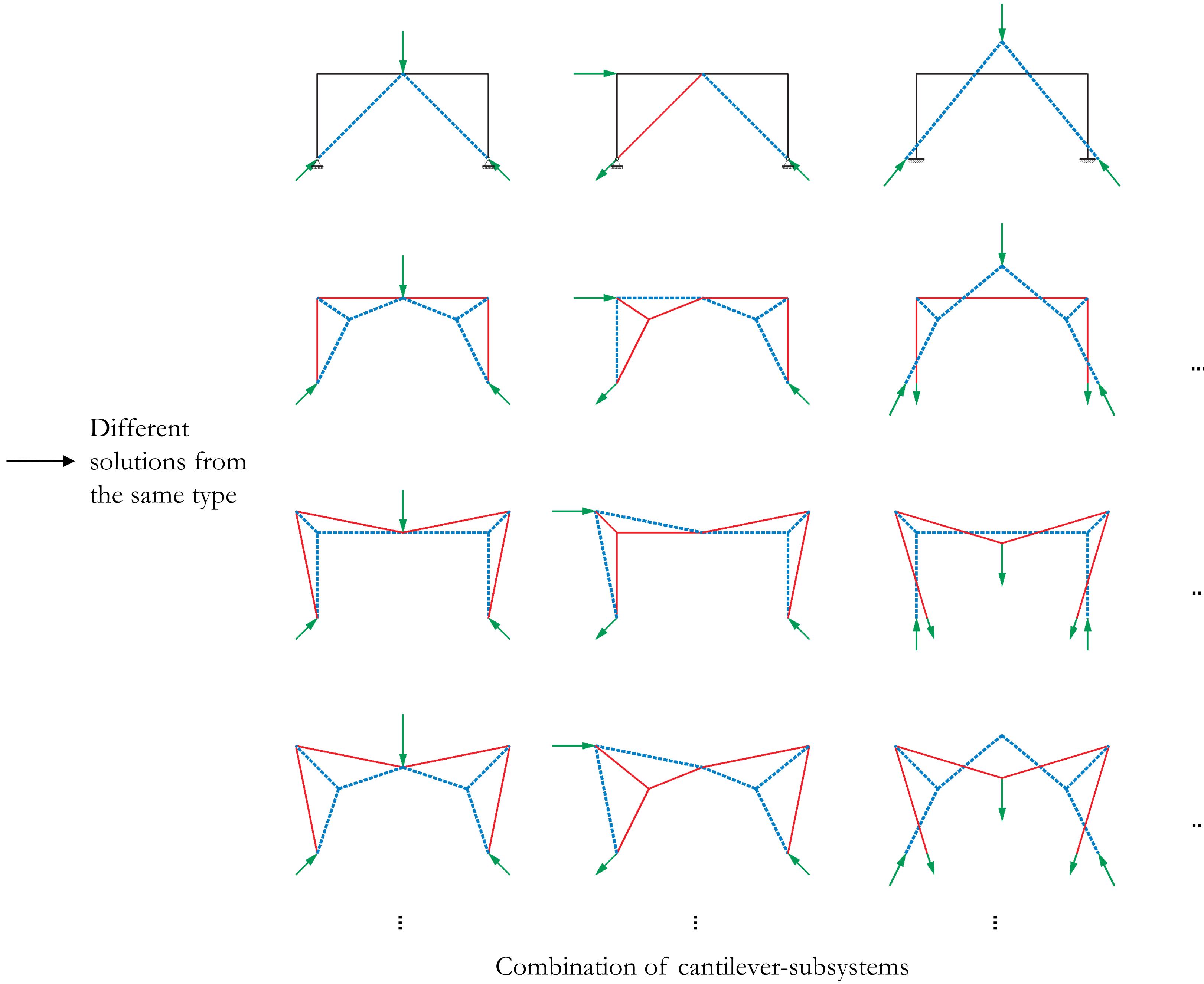
Arch-cable system

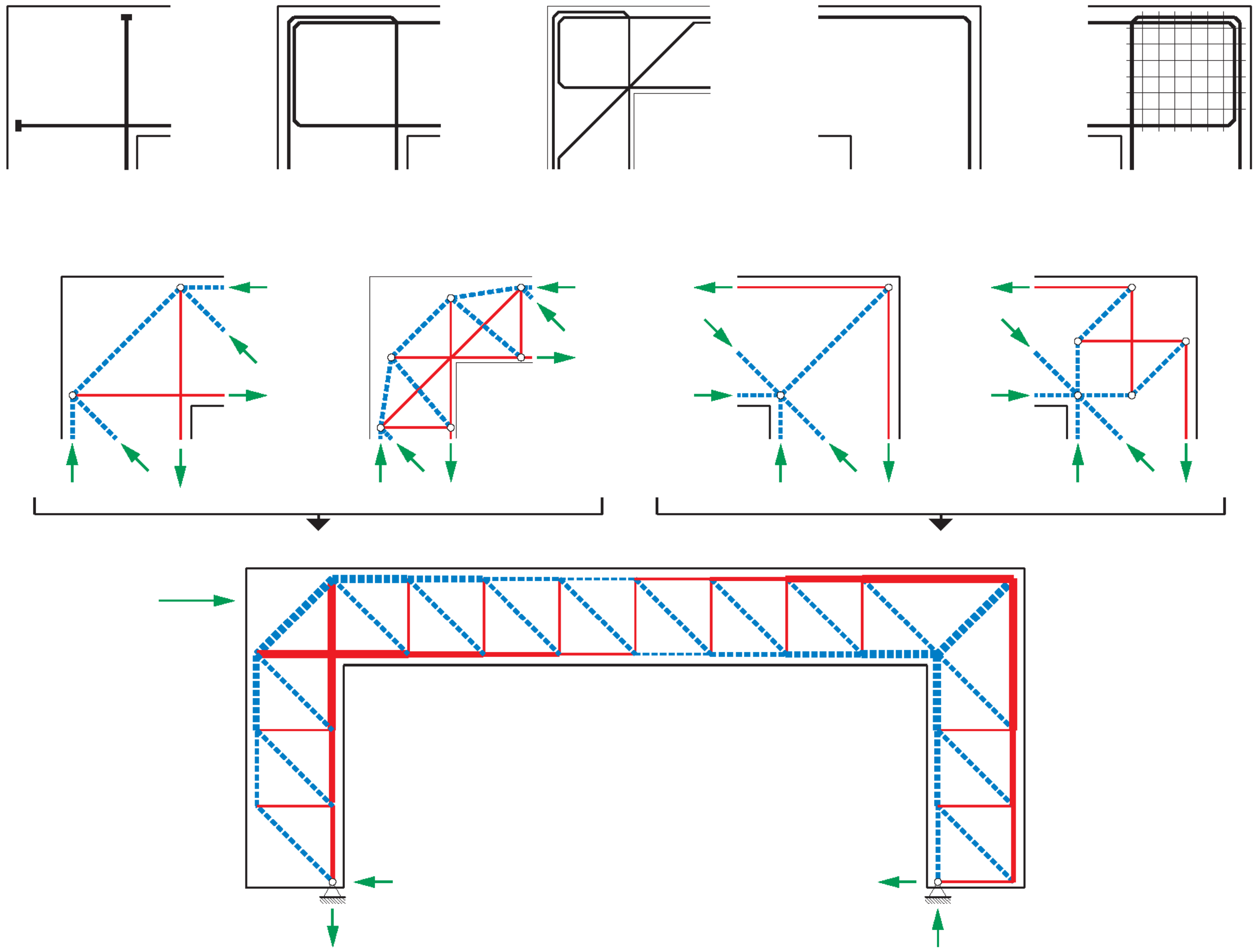
Strut-and-tie model

Stress field

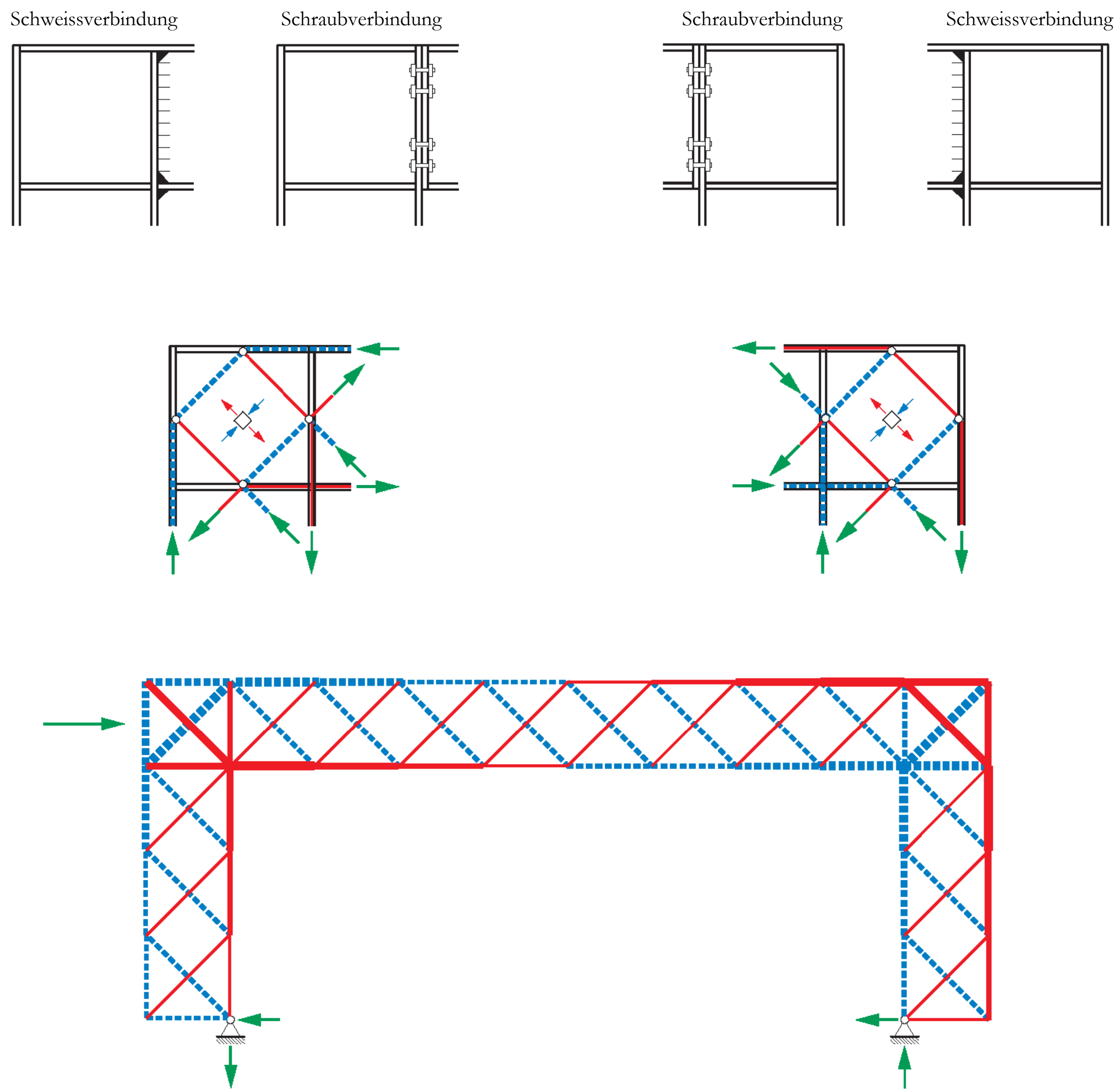


Source: Aurelio Muttoni, Joseph Schwartz, Bruno Thürlimann, Design of concrete structures with stress fields, 1996

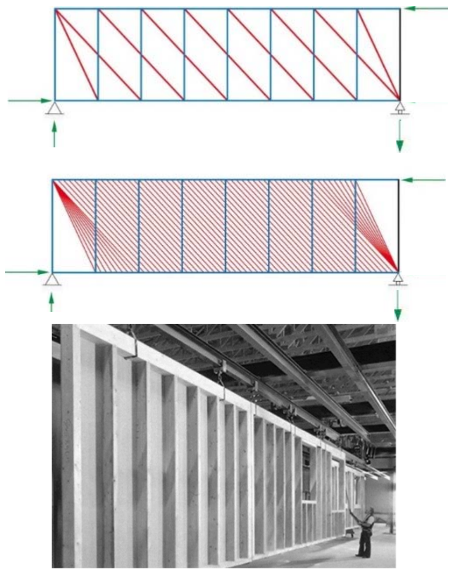

Different solutions from the same type
...
Combination of cantilever-subsystems



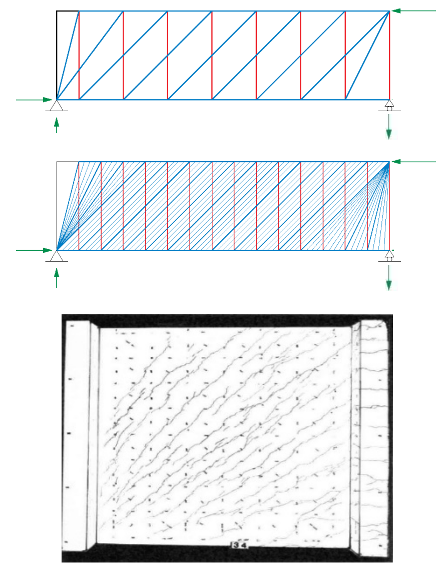
Studio Vacchini: Sportausbildungszentrum Mulimatt in Brugg


Schweissverbindung
Schraubverbindung
Schraubverbindung
Schweissverbindung

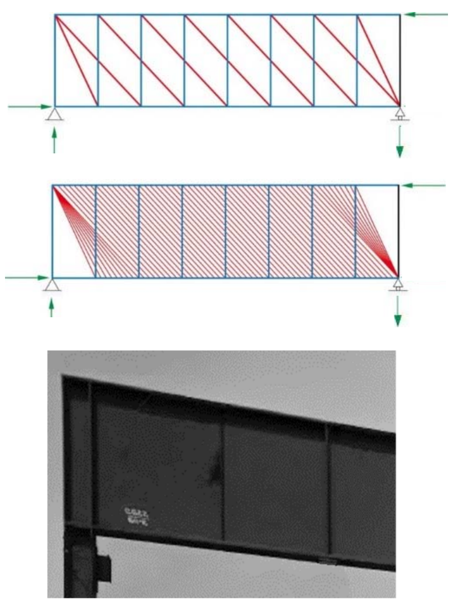
L. Mies van der Rohe: Crown Hall IIT in Chicago



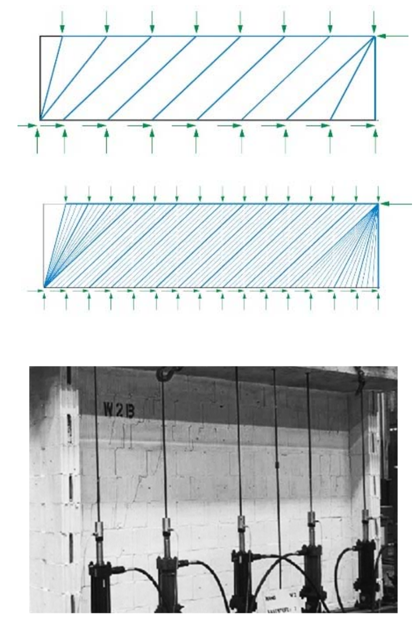
Timber



Reinforced Concrete



Steel



Masonry

Structural Typologies

Cable structures

Arches and shells

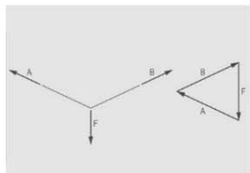
Arch-cable systems

Trusses

Beams

Frames

1. Equilibrium

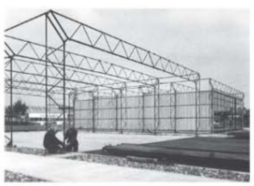


2. Graphic Statics

3. Cables

4. Arches

5. Arch-Cable Structures



6. Trusses

7. Beams

8. Frames

9. Slabs

10. Columns

Structural Typologies

Cable structures

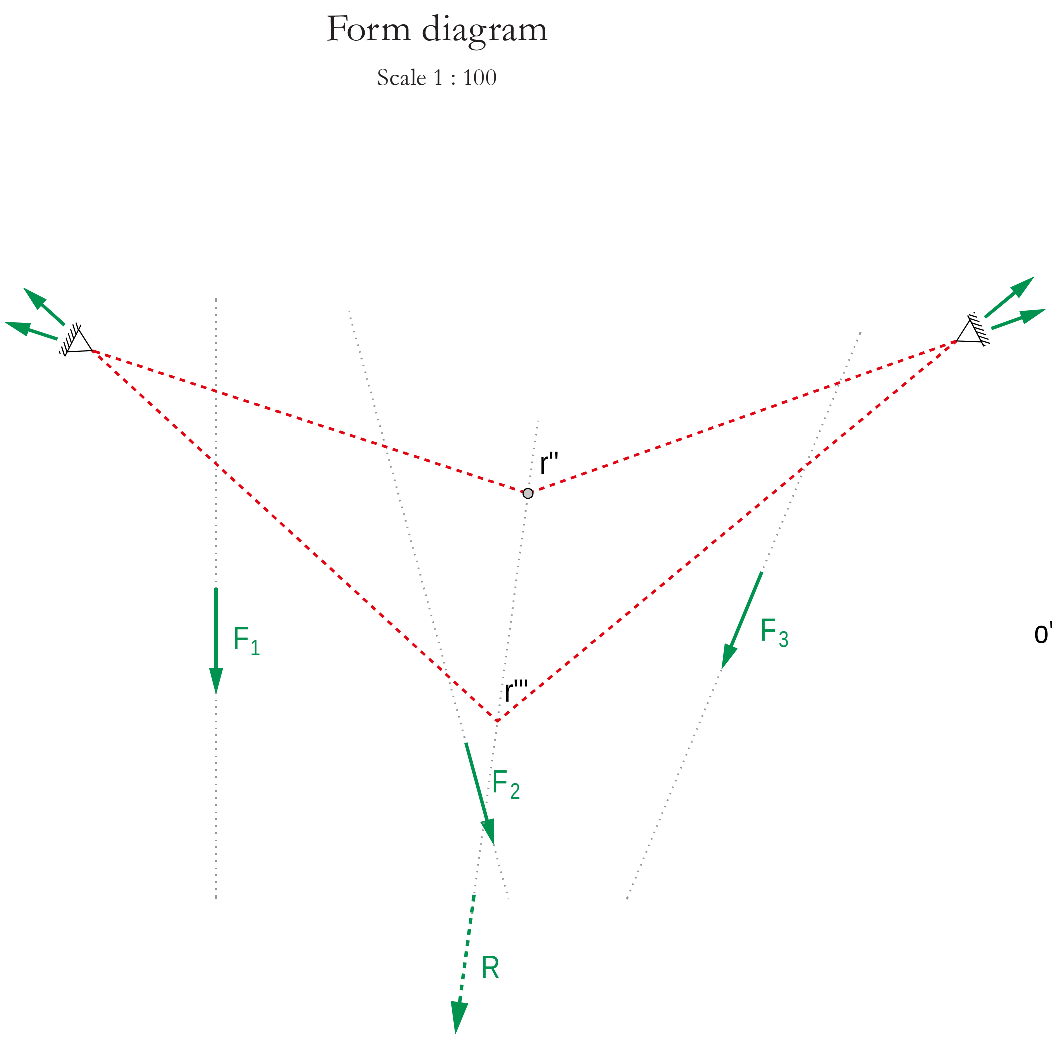
Arches and shells

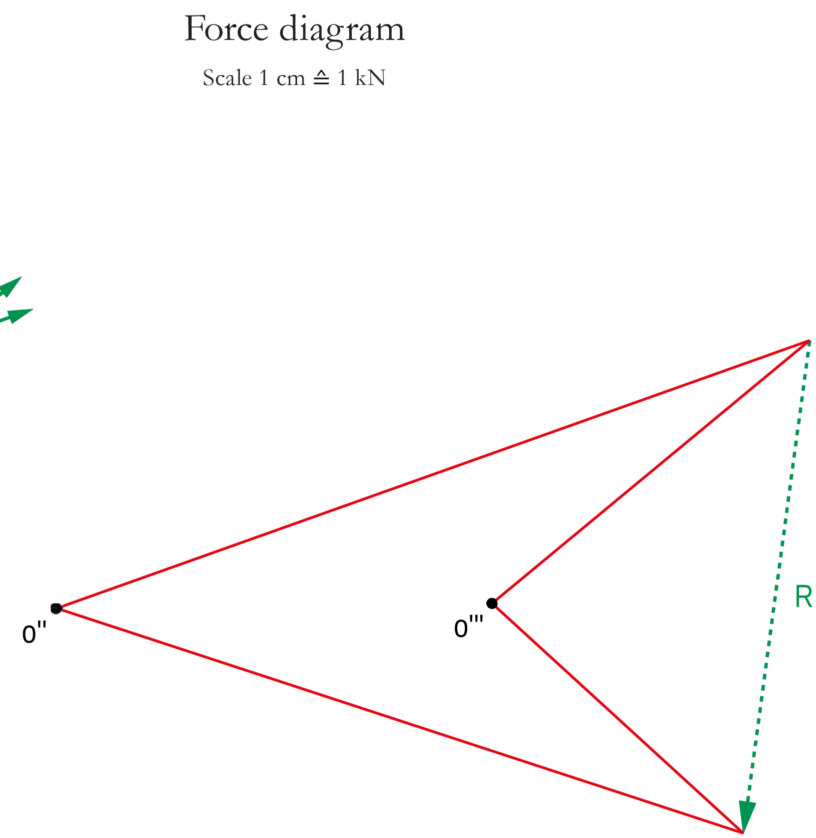
Arch-cable systems

Trusses

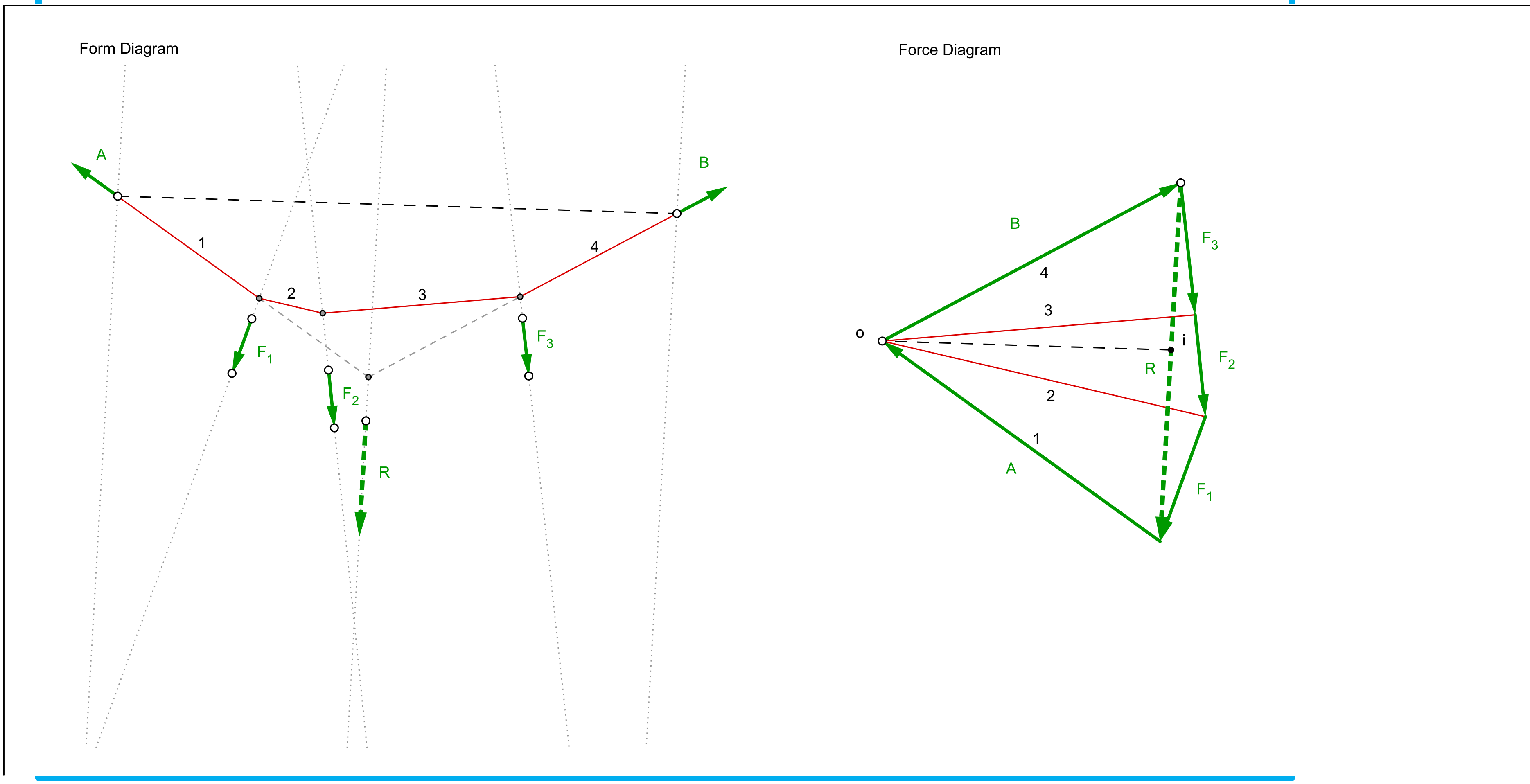
Beams

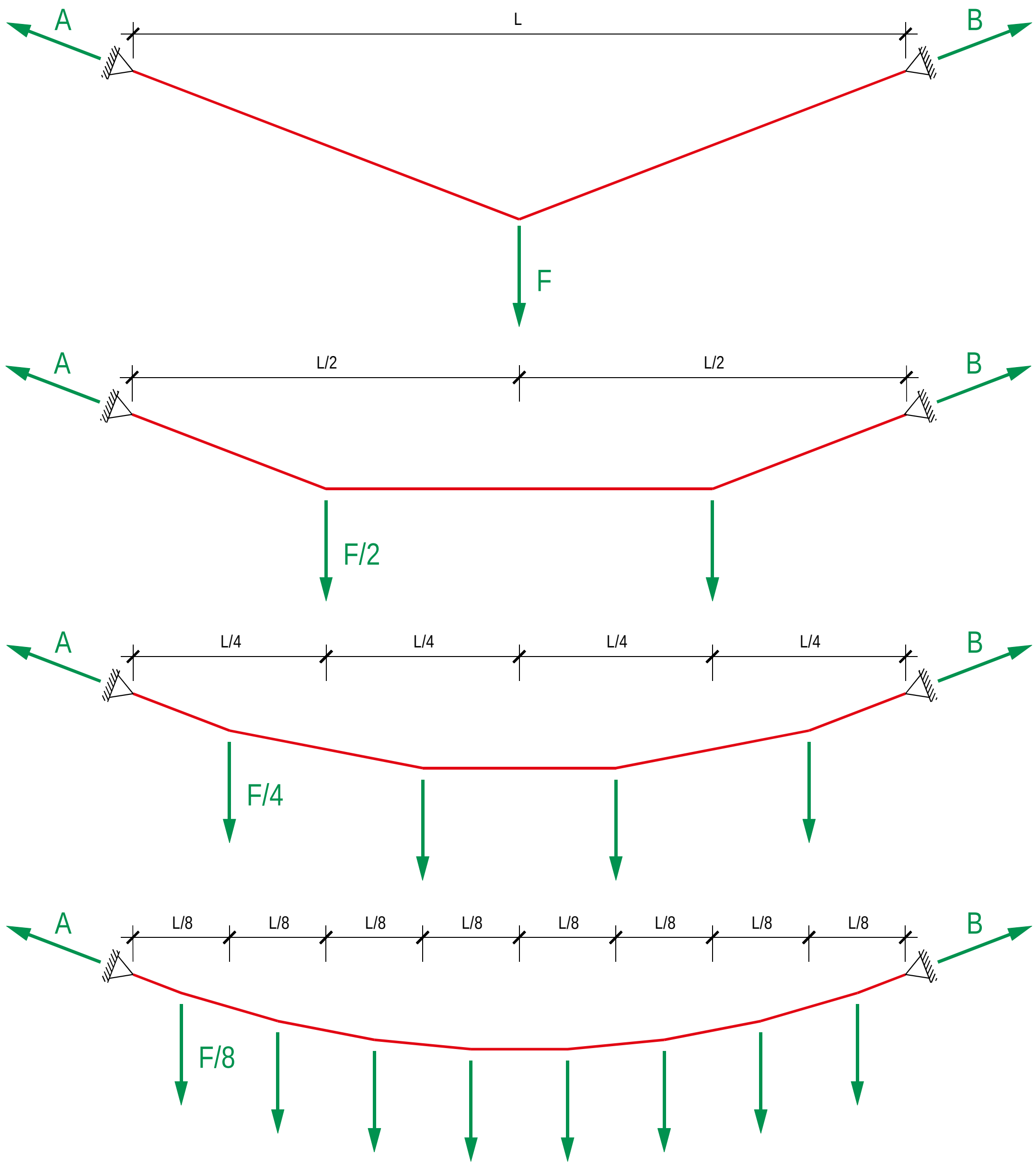
Frames


Form diagram
Scale 1 : 100
r''
r'''
F1
F2
F3
R

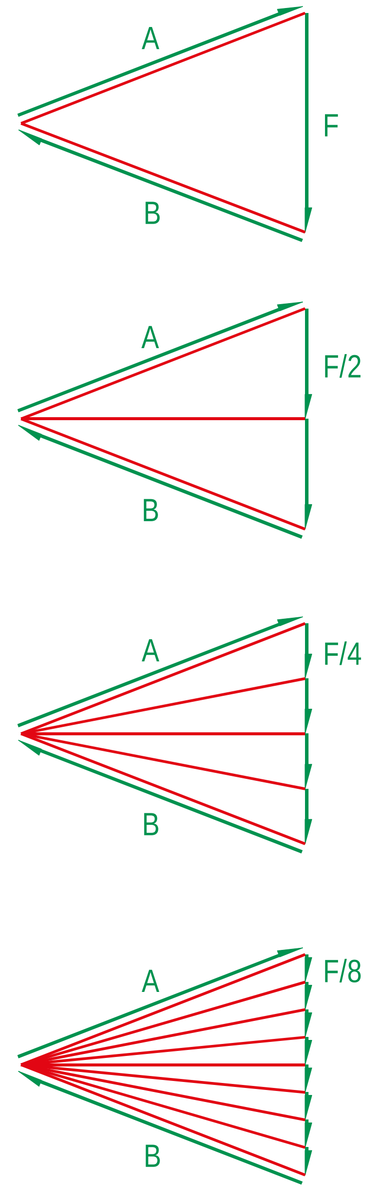

Force diagram
Scale 1 cm ≙ 1 kN
o''
o'''
R

eQ: Funicular line through two points

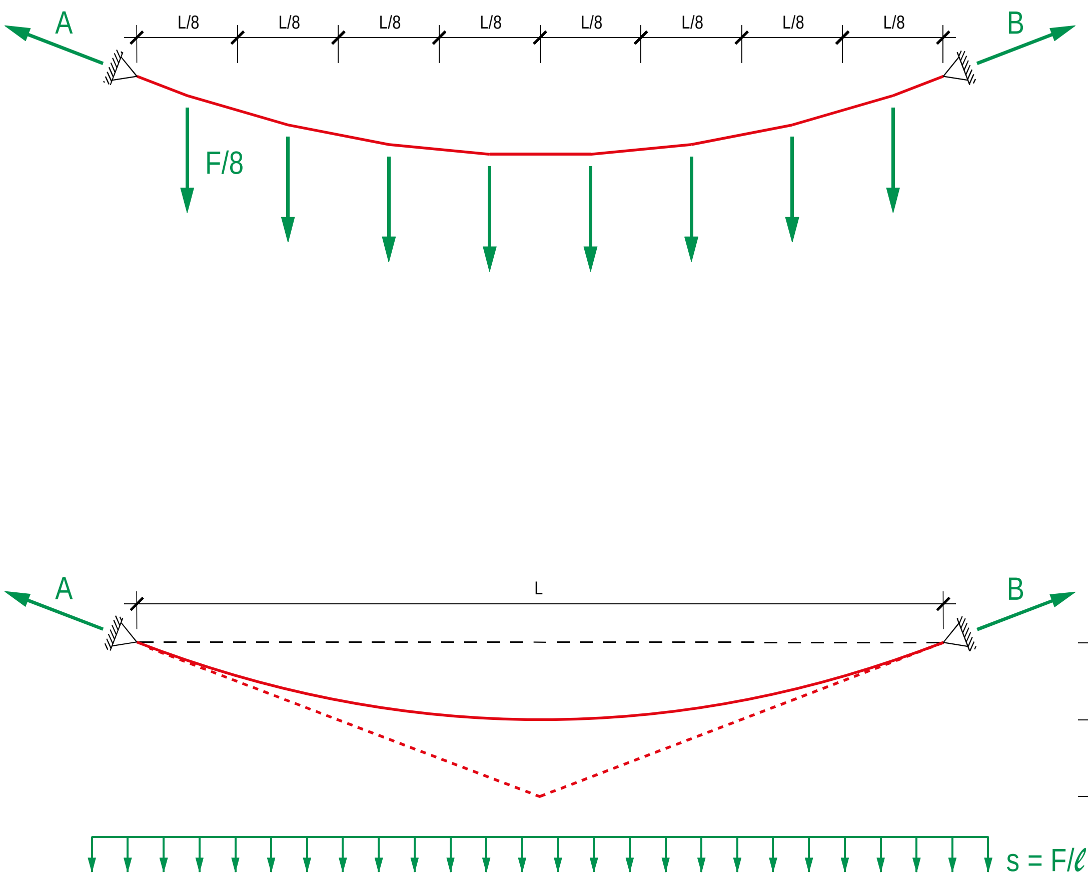




Form diagram

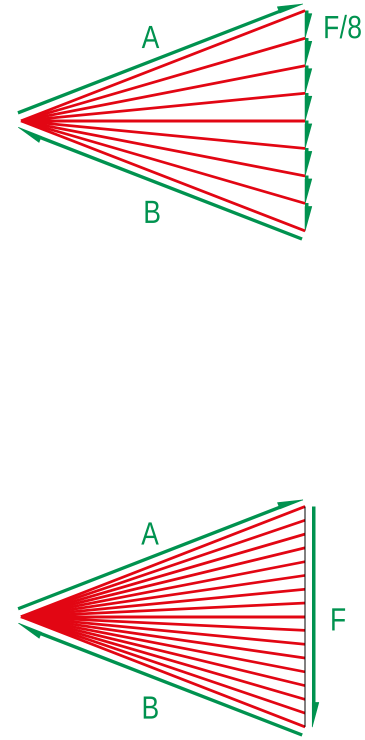


Force diagram



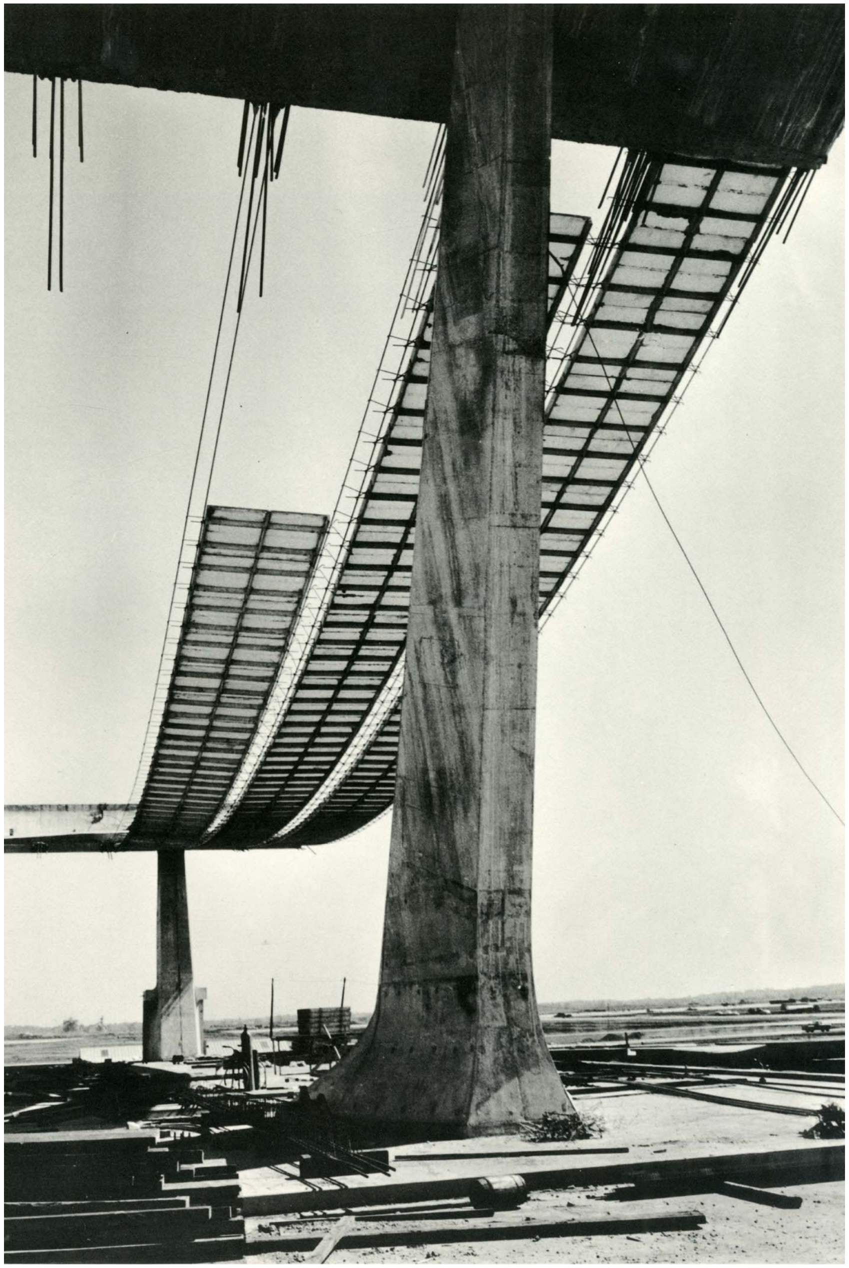
Form diagram

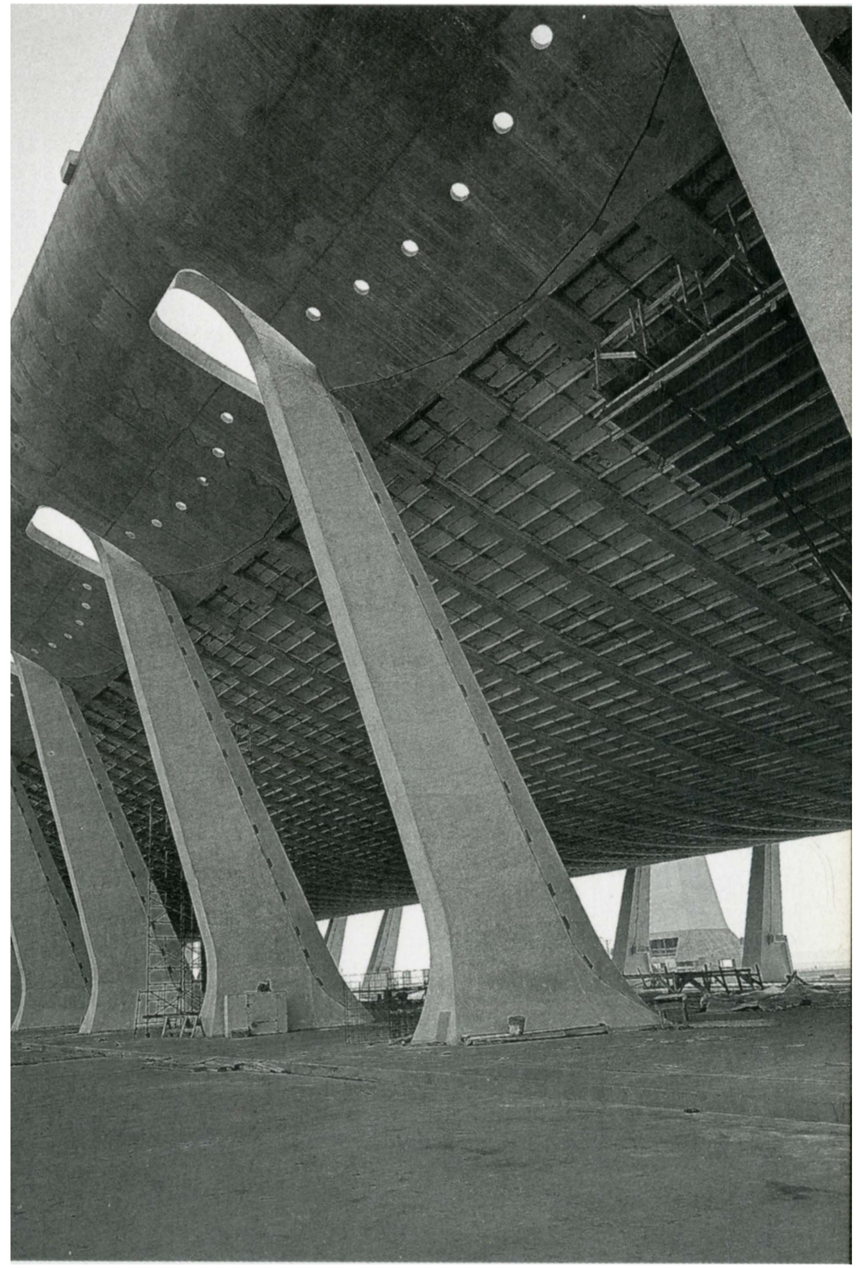
Scale 1 : 100



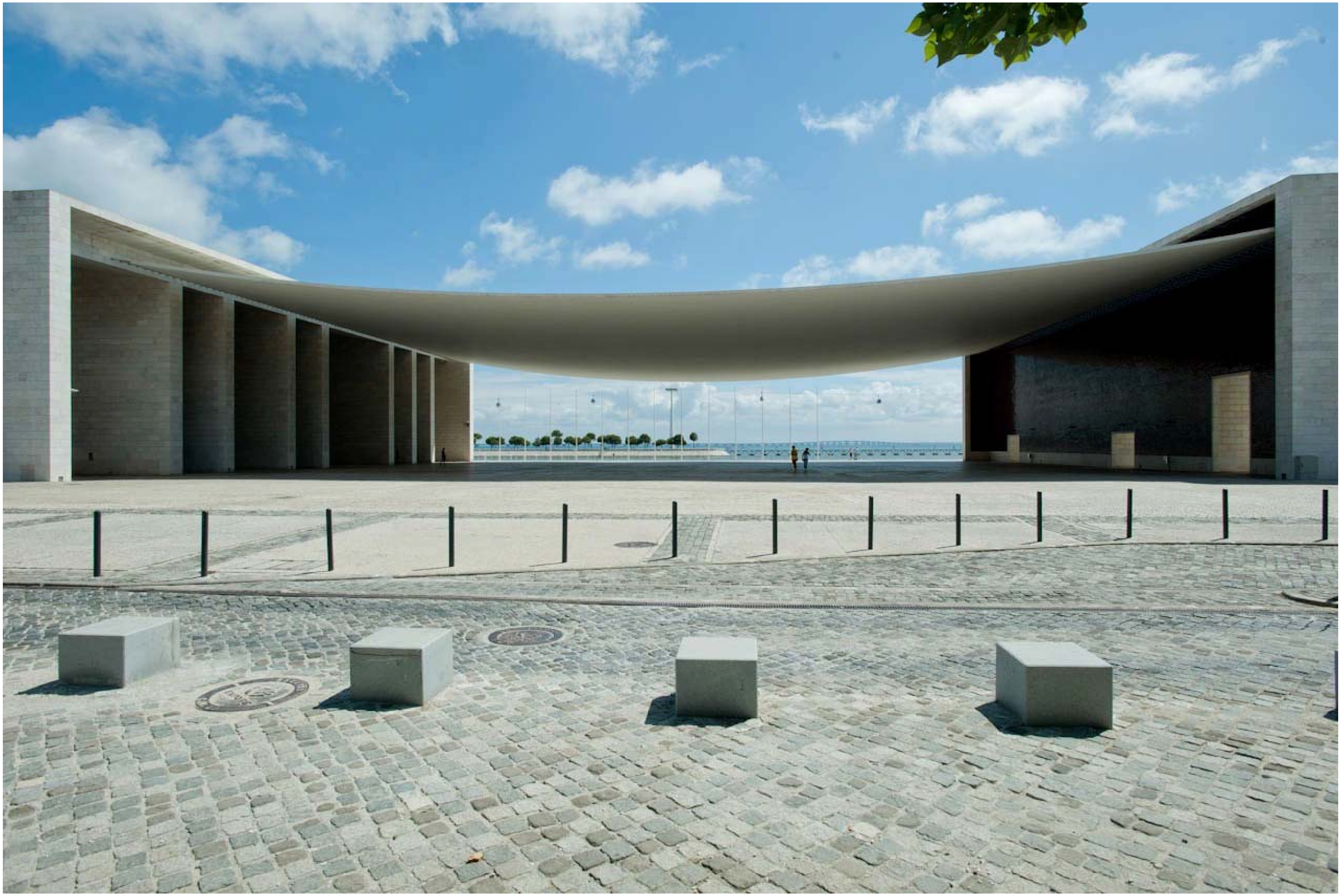
Force diagram

Scale 1 cm ≙ 1 kN

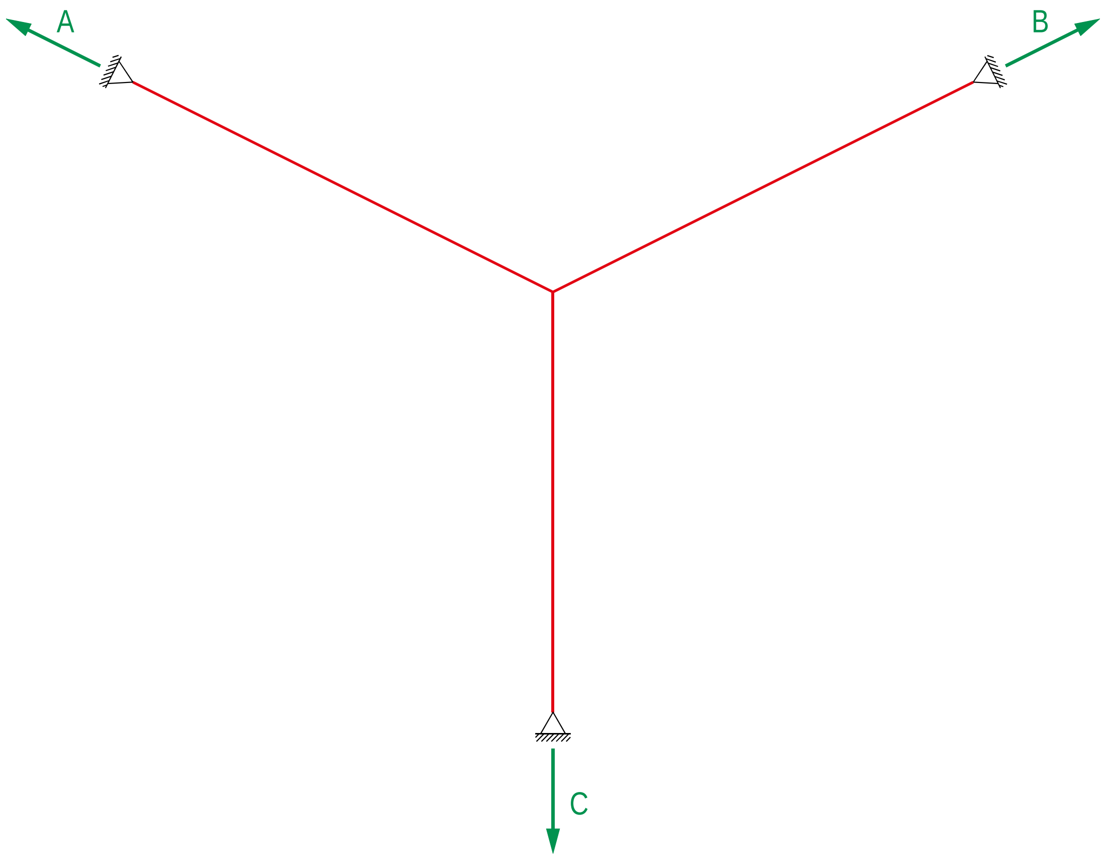


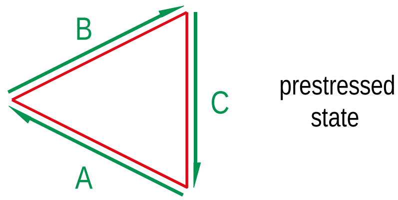


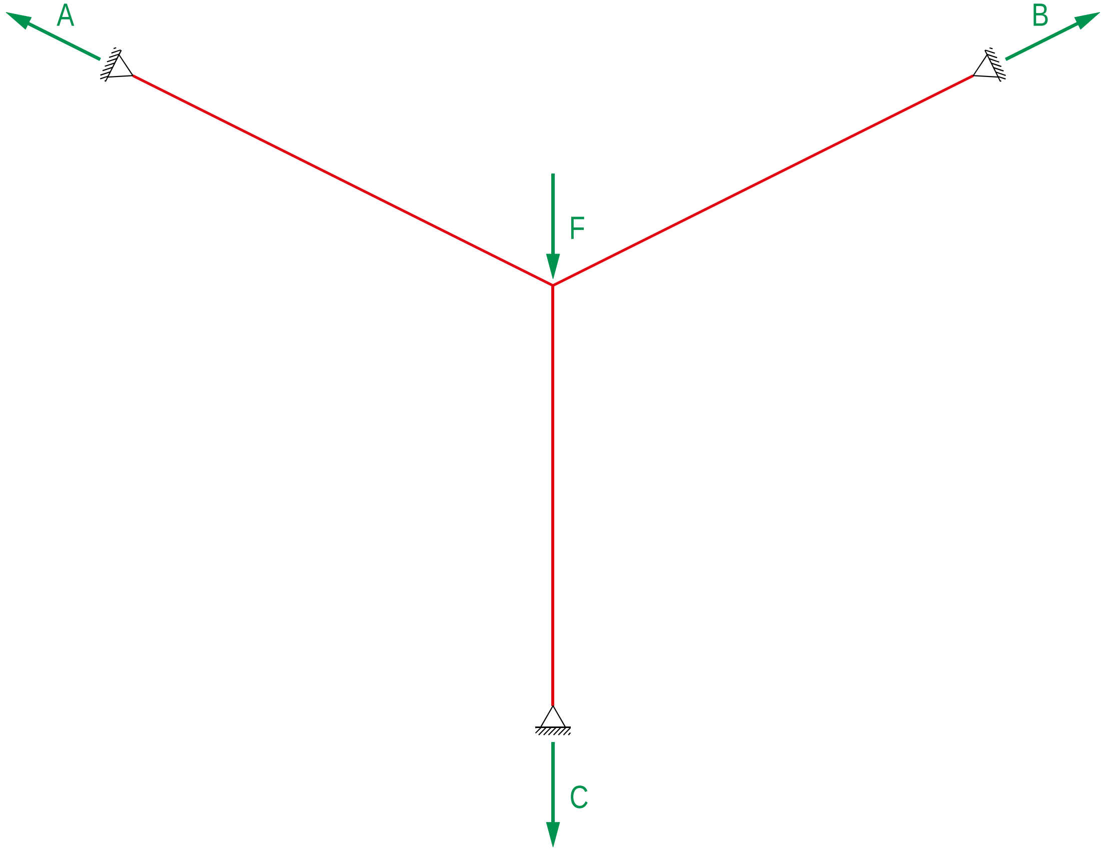
Eero Saarinen: Dulles International Airport, Washington, 1962



Alvaro Siza, Cecil Balmond : Expo Pavillion of Portugal, Lissabon, 1998


A
B
C


B
C
A
prestressed
state


A
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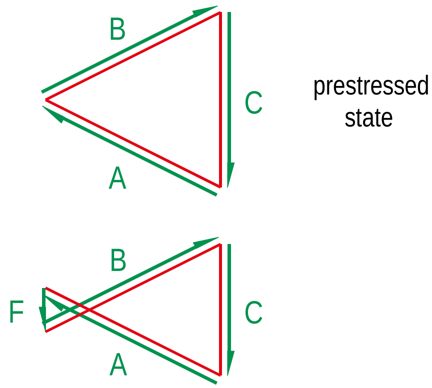
F
C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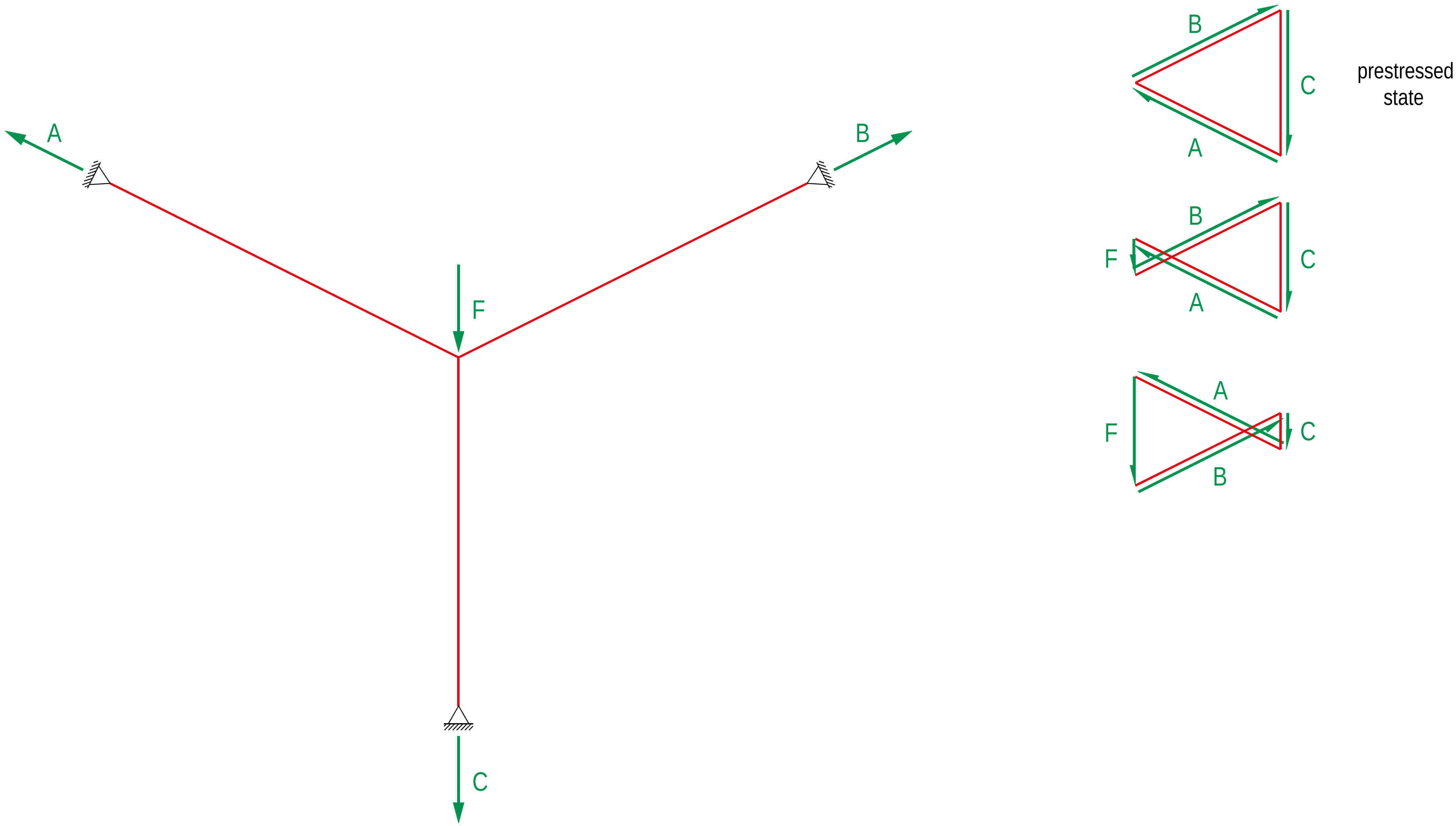
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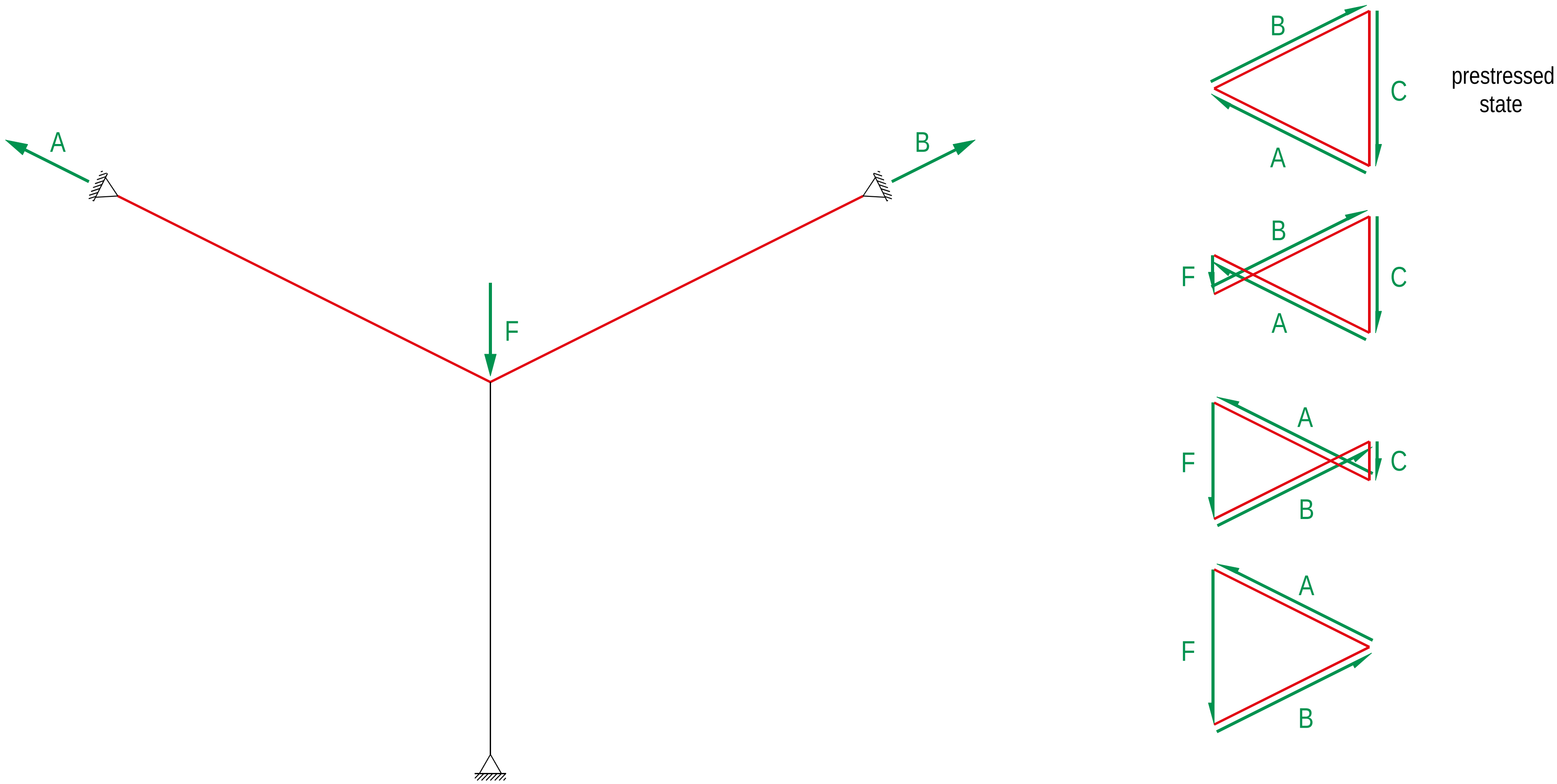
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prestressed state
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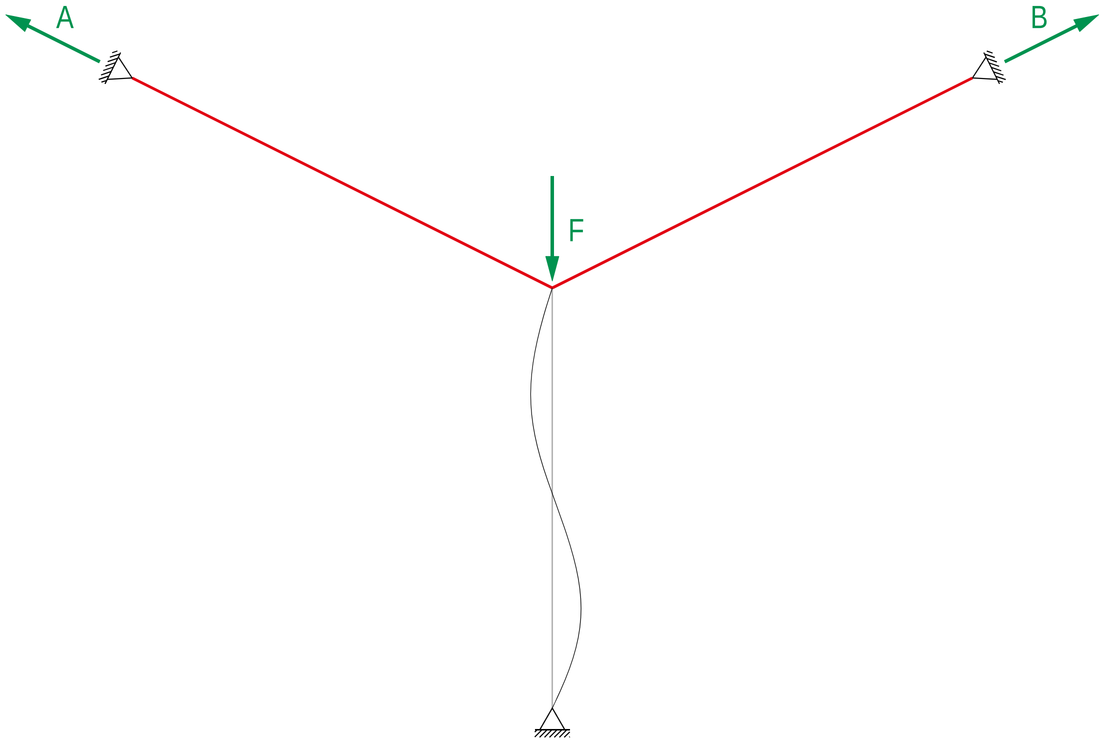
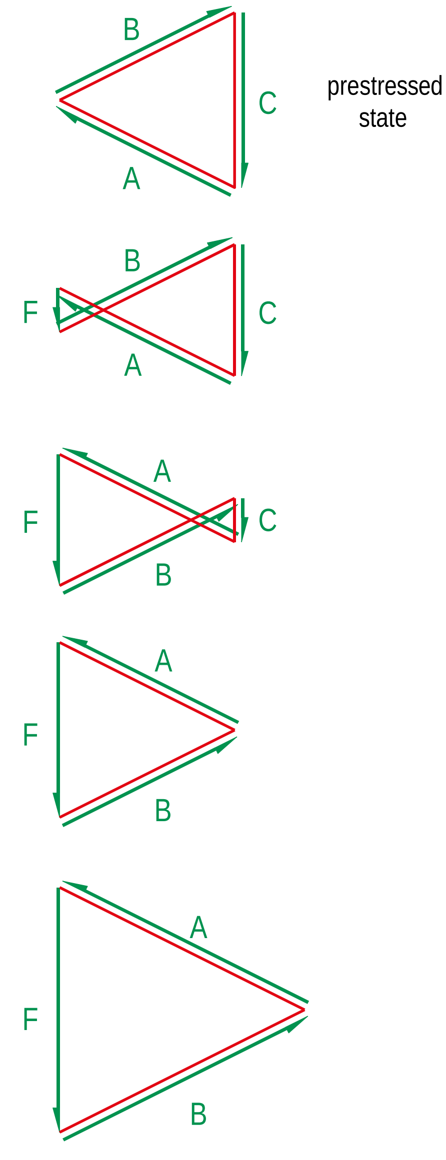

A
B
F


B
C
A
prestressed state
B
F
C
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A
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C
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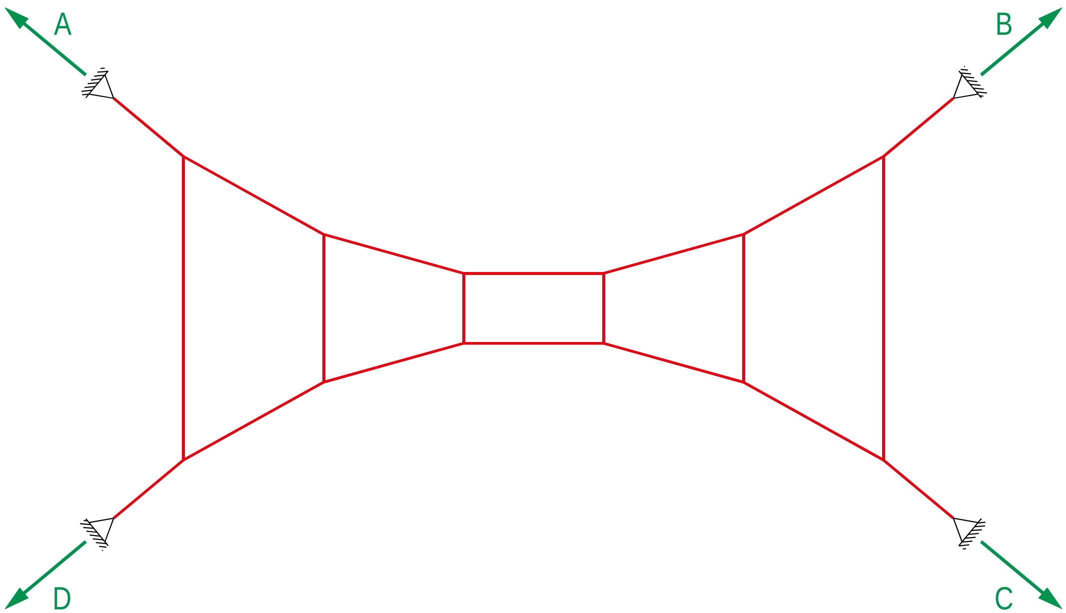
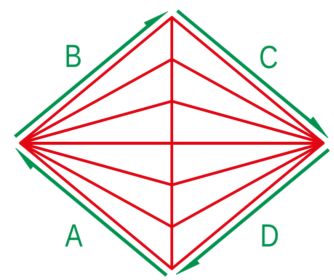
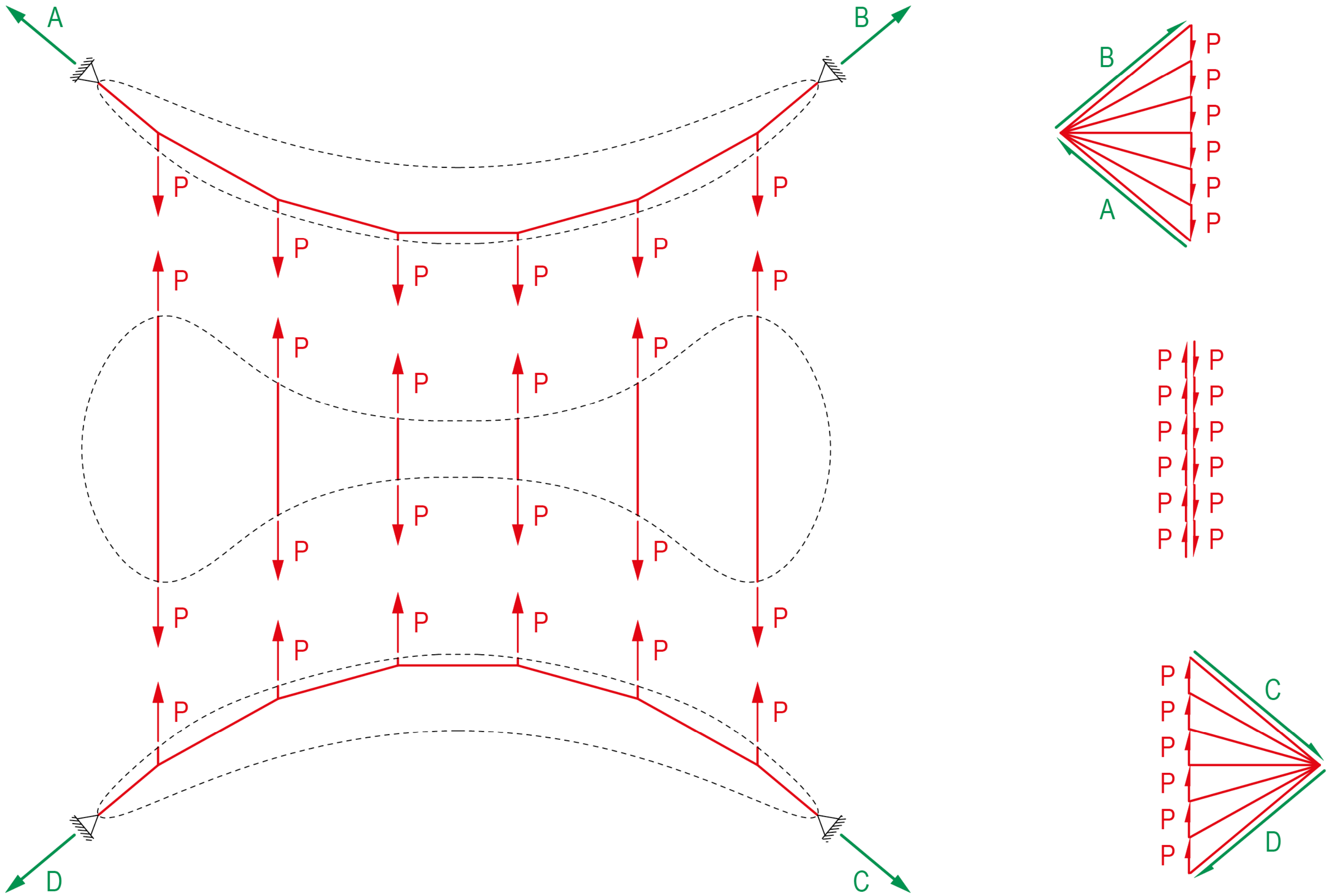
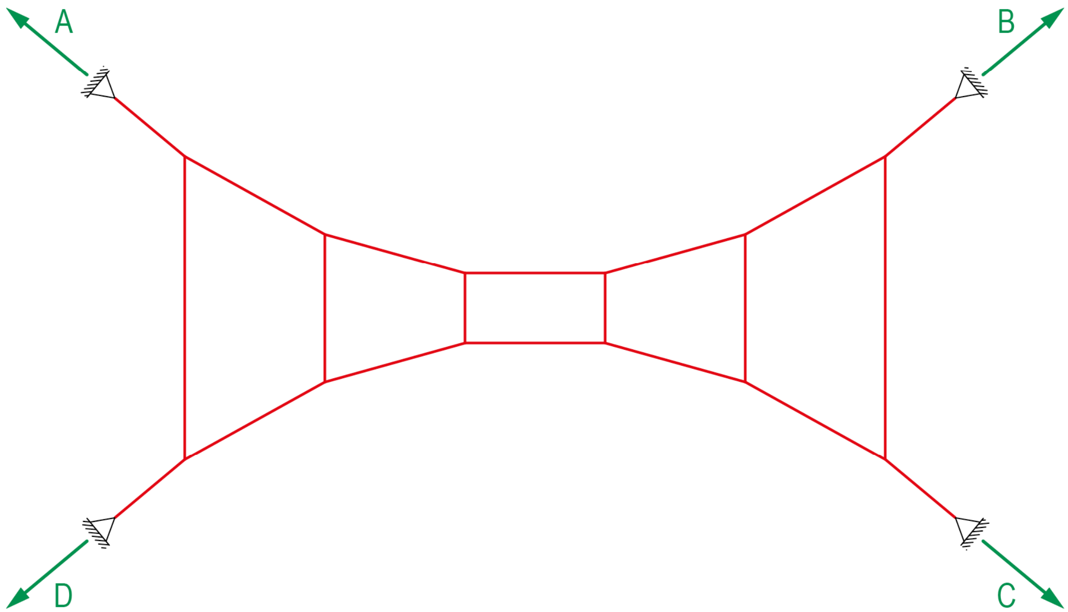
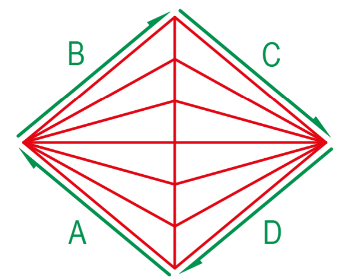
B
A
F
B

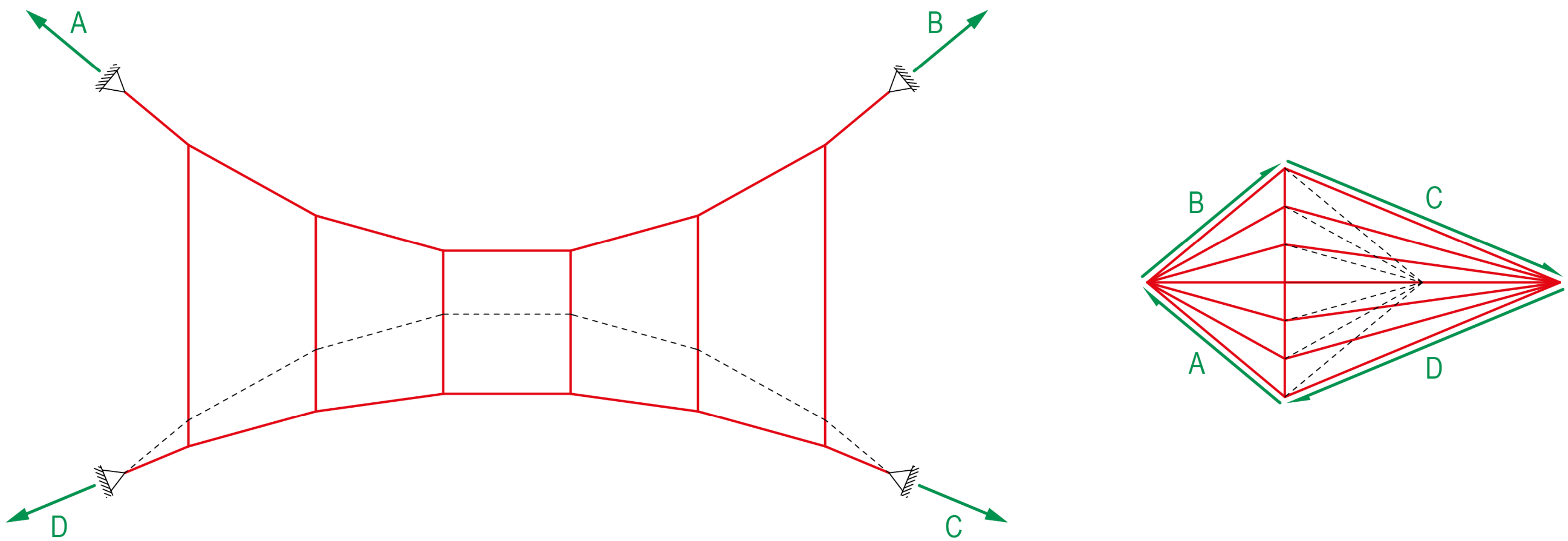

A
B
D
C


B
C
A
D

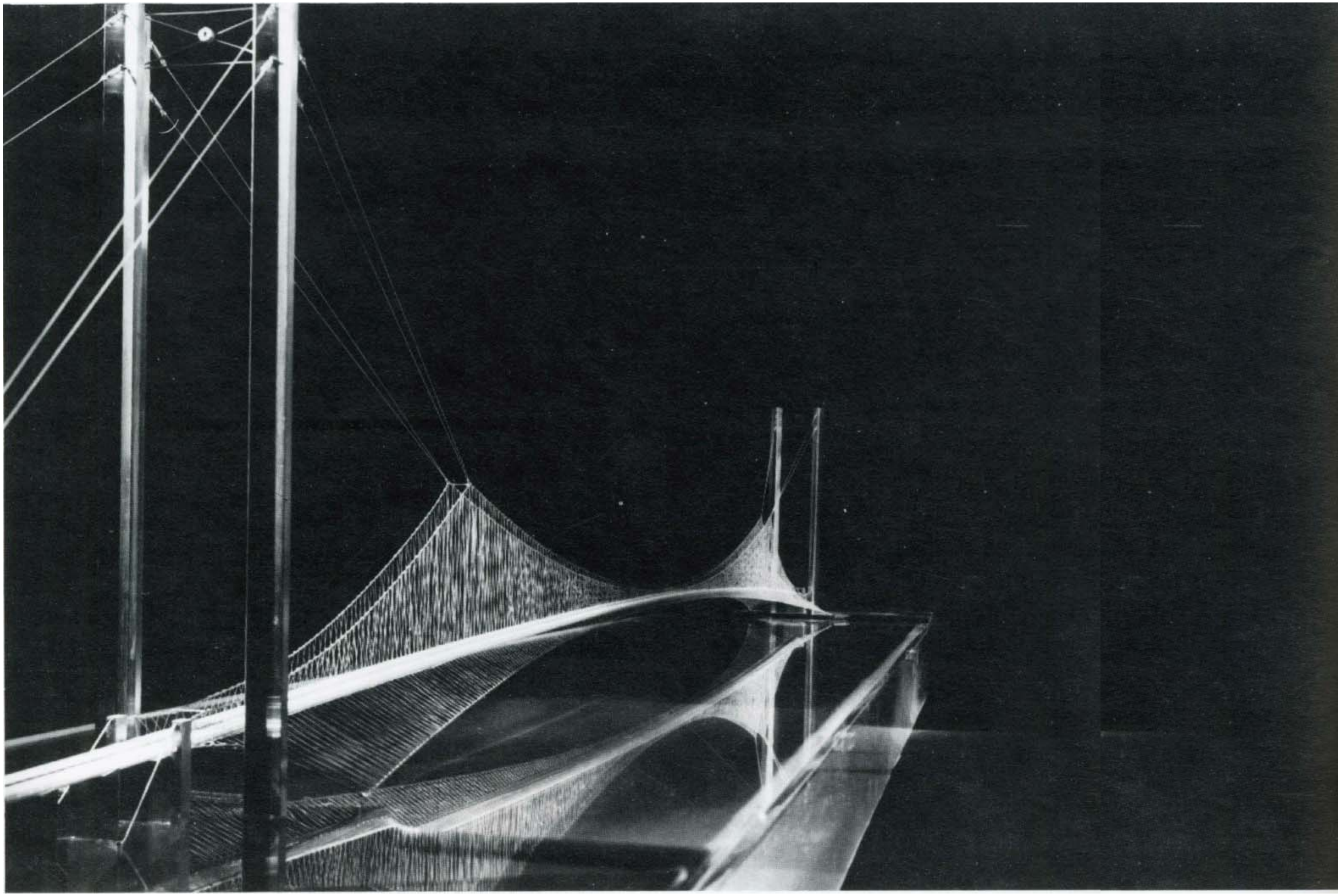

A
B
C
D
P


A
B
D
C

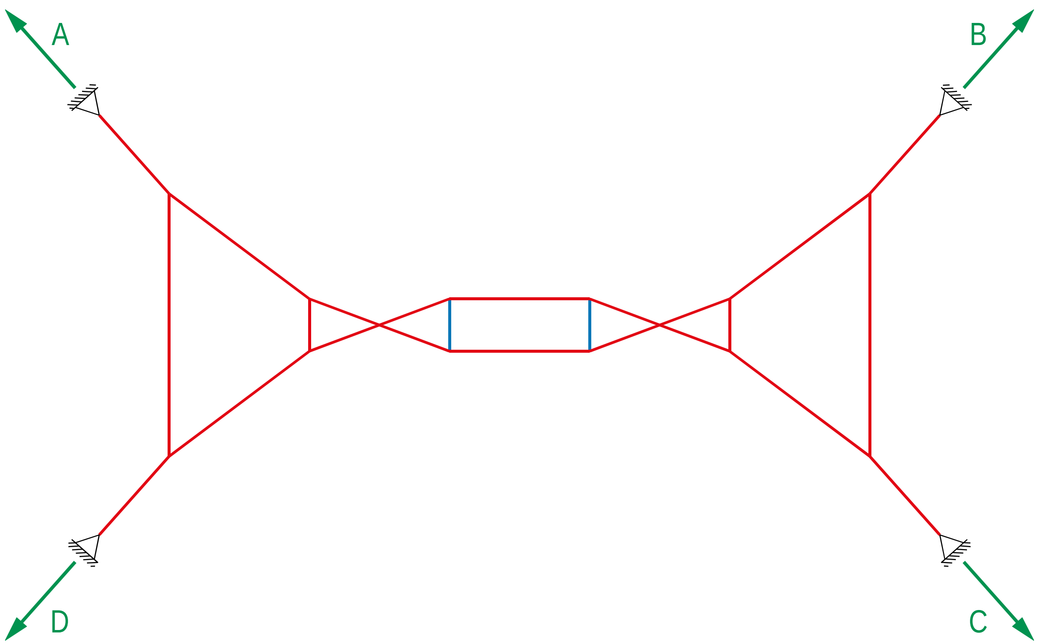

B
C
A
D

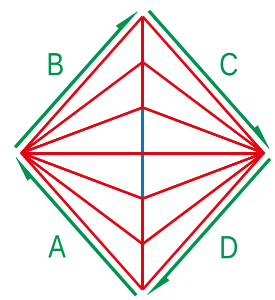

A
B
D
C
B
C
A
D

Veil & Jörg Steli, Thomas Zoidl, pedestrian bridge Bruneck, Innsbruck, 2004

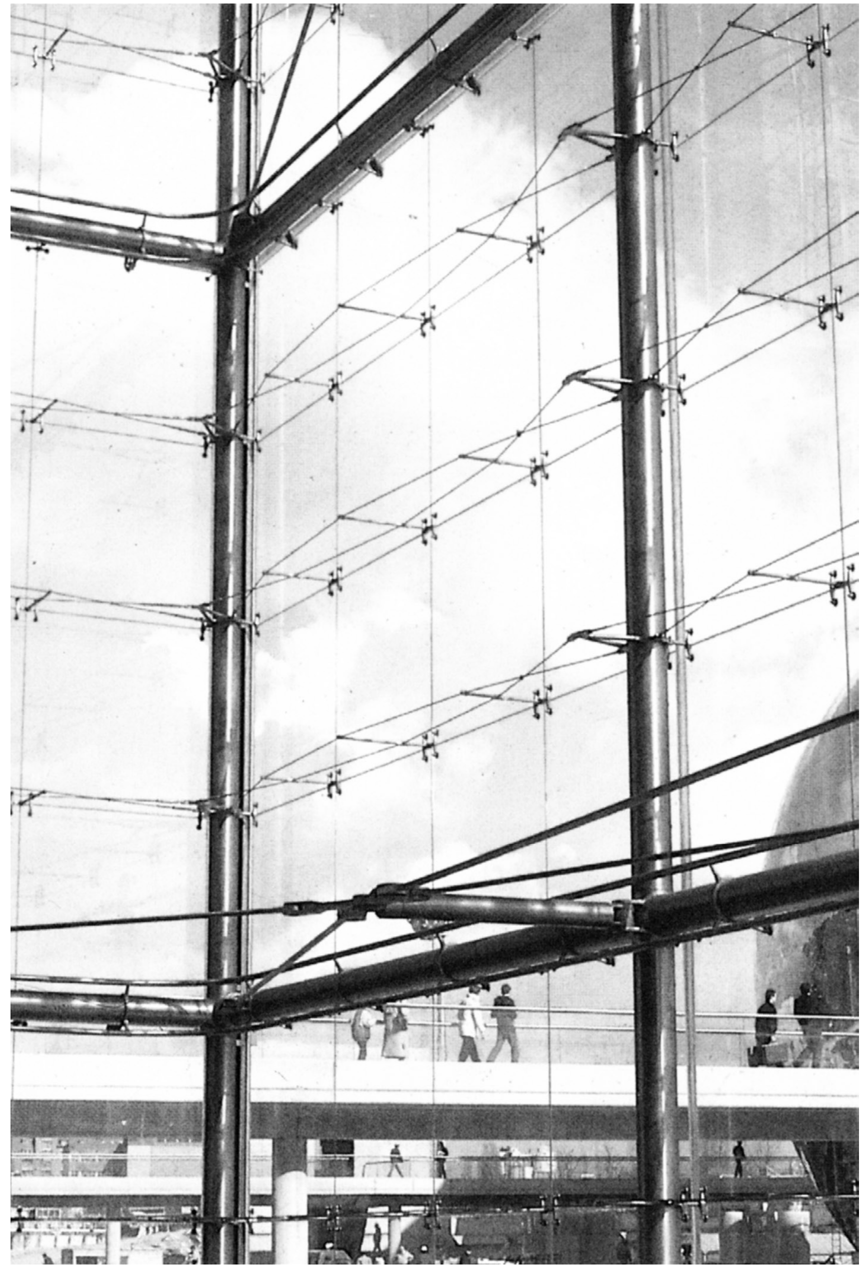


Sergio Musmeci, competition for Ponte sullo Stretto di Messina, 1970

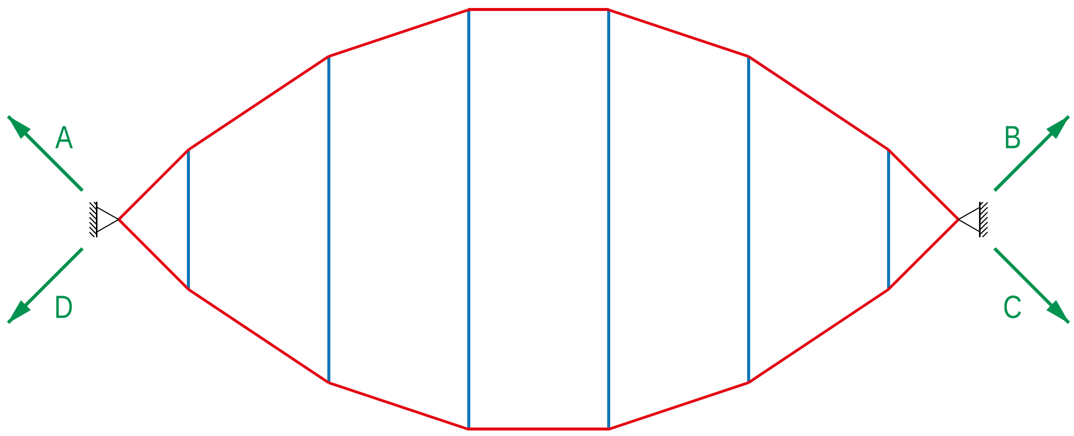

A
B
D
C

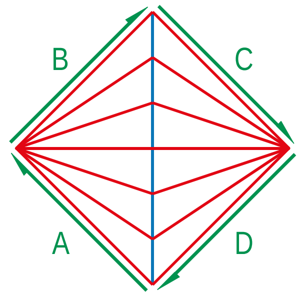

B
C
A
D

Peter Rice, Arup: Fingal Country Council. Dublin, 2002

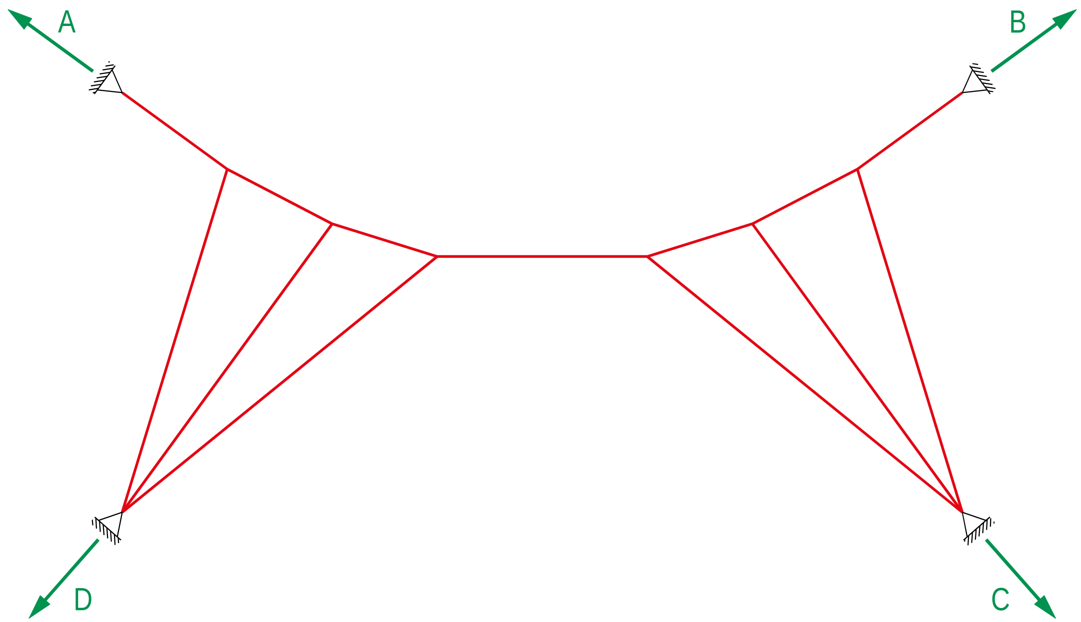


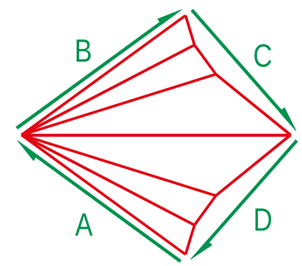
Peter Rice: Serres de la Villette. Paris, 1982


A
D
B
C

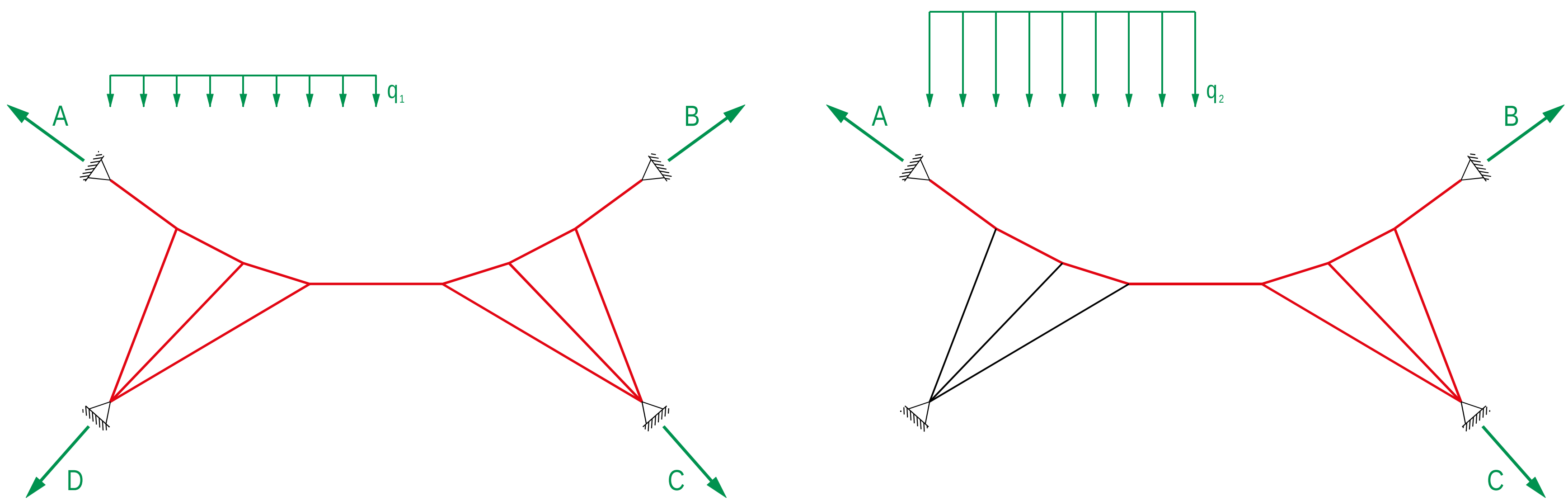

B
C
A
D

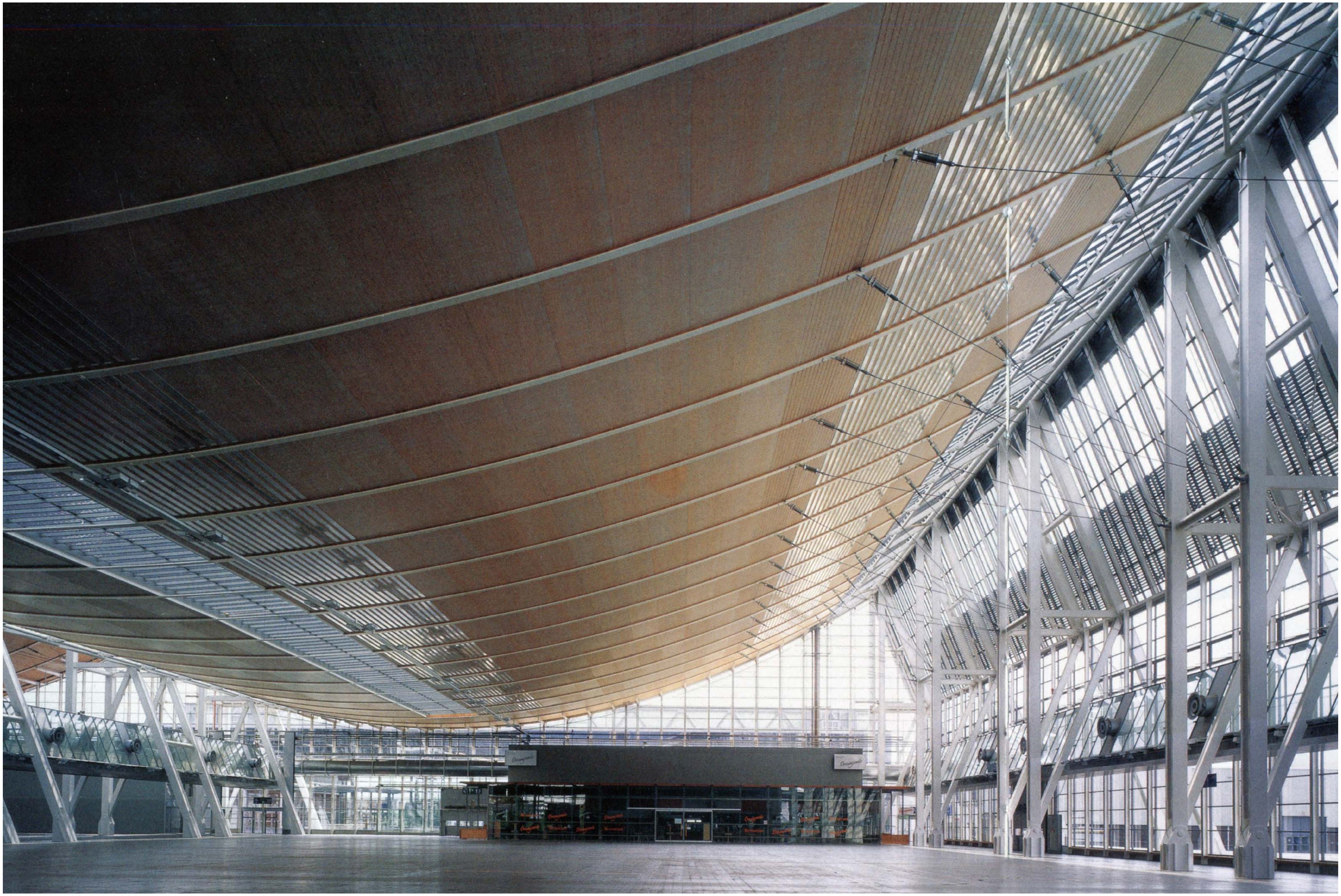
Renzo Piano: Kansai International Airport. Osaka, 1994


A
B
D
C

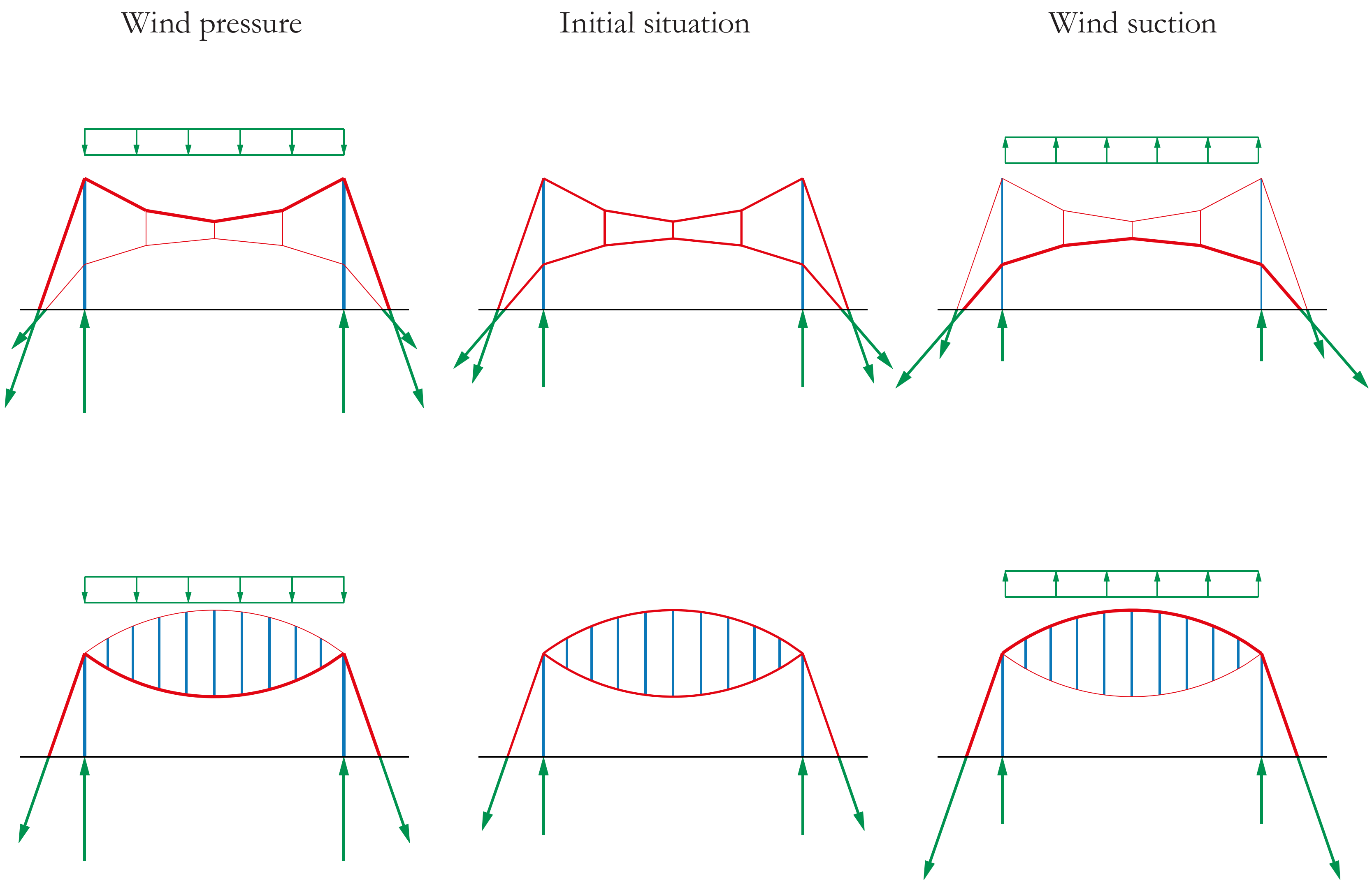

B
C
A
D

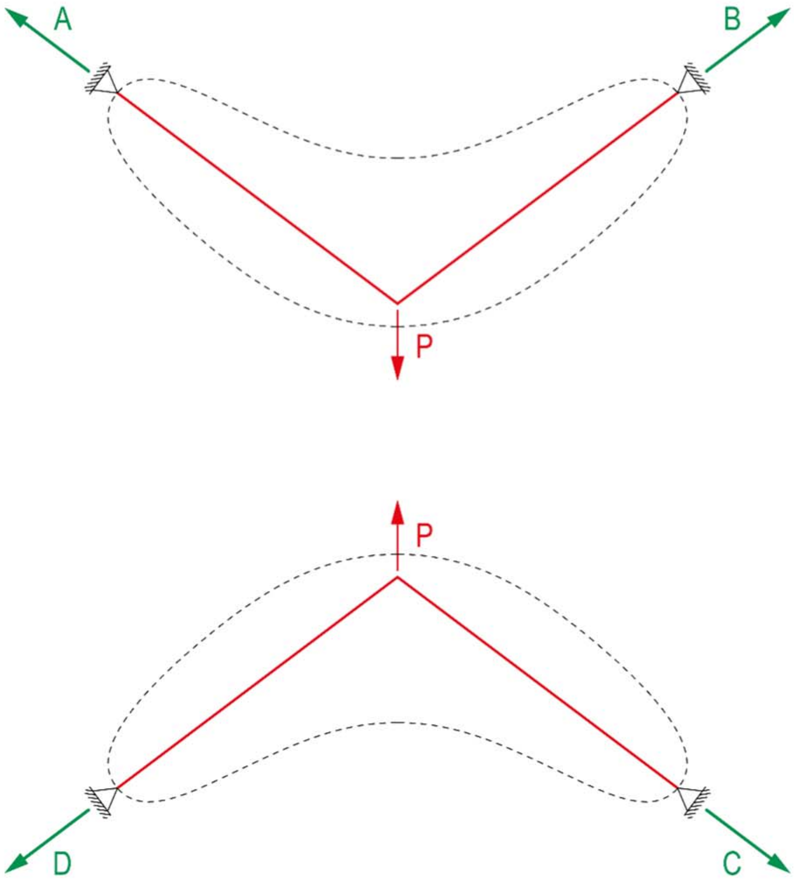
$$q_1 < q_2$$

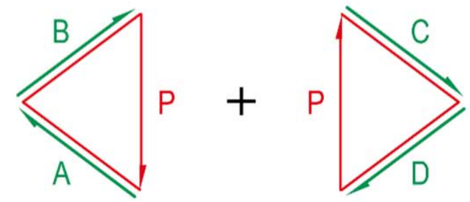


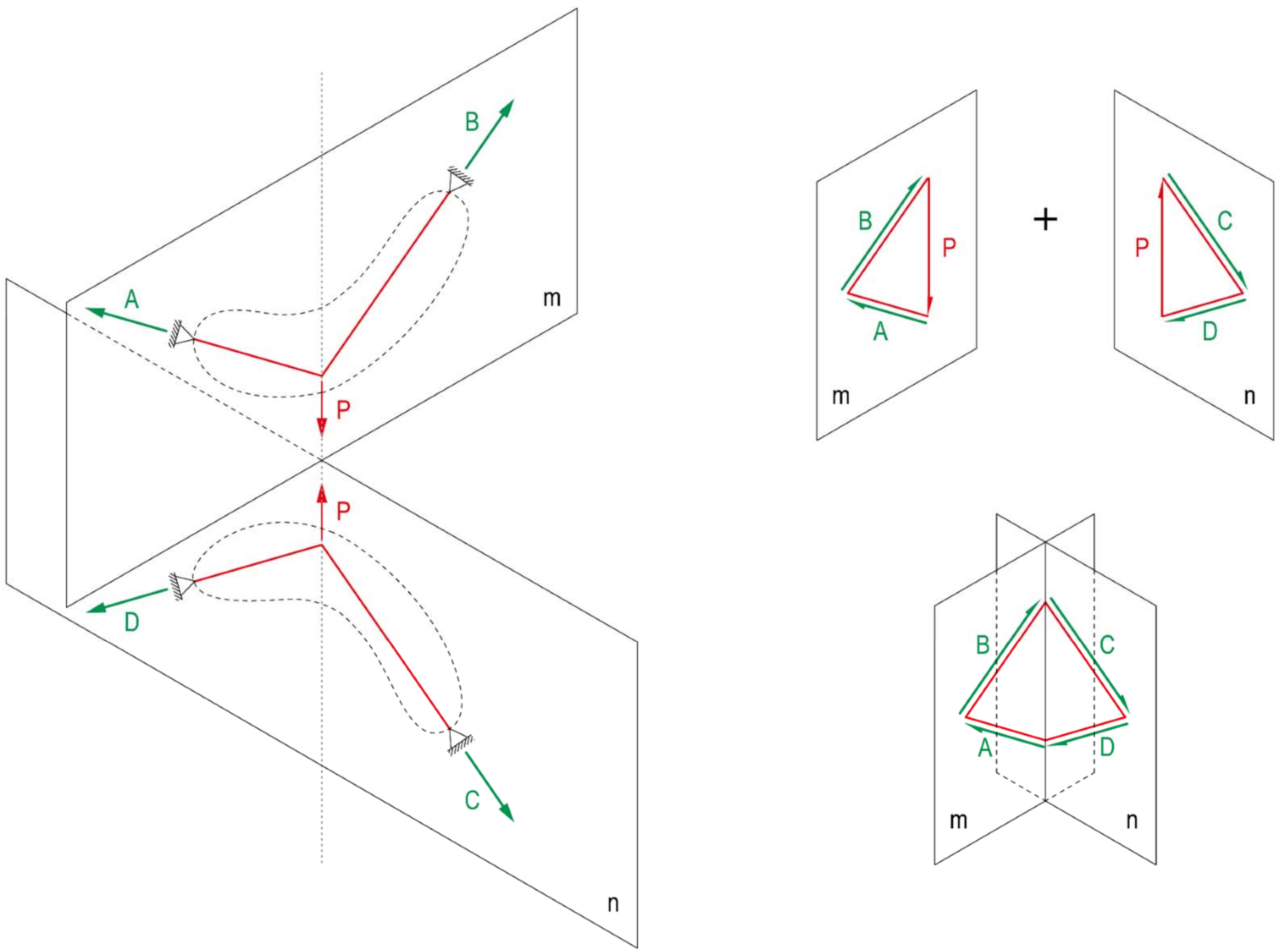


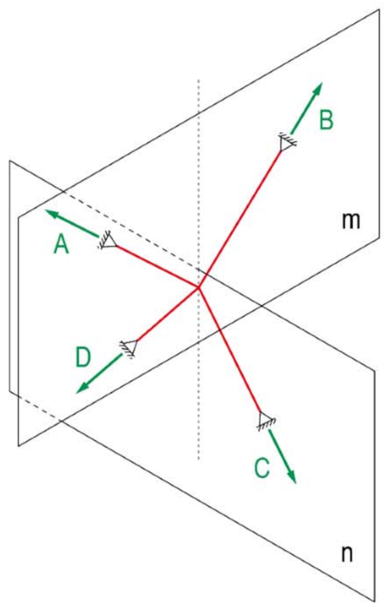
Herzog and Partner, Schlaich Bergermann and Partner: Exhibition center 26, Hannover, 1996

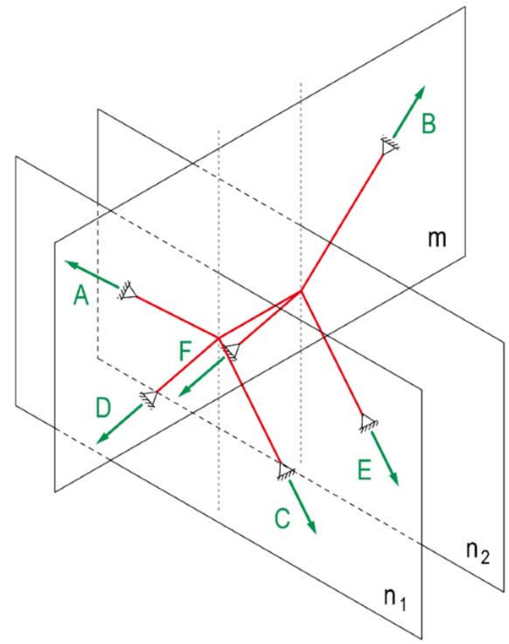

Wind pressure
Initial situation
Wind suction

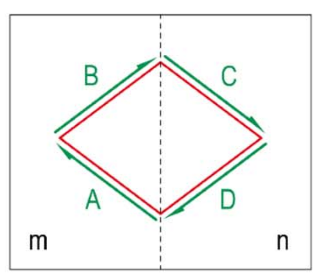

A
B
P
P
D
C

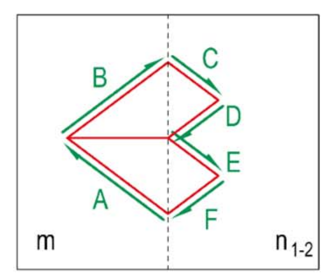

B
P
A
+
C
P
D

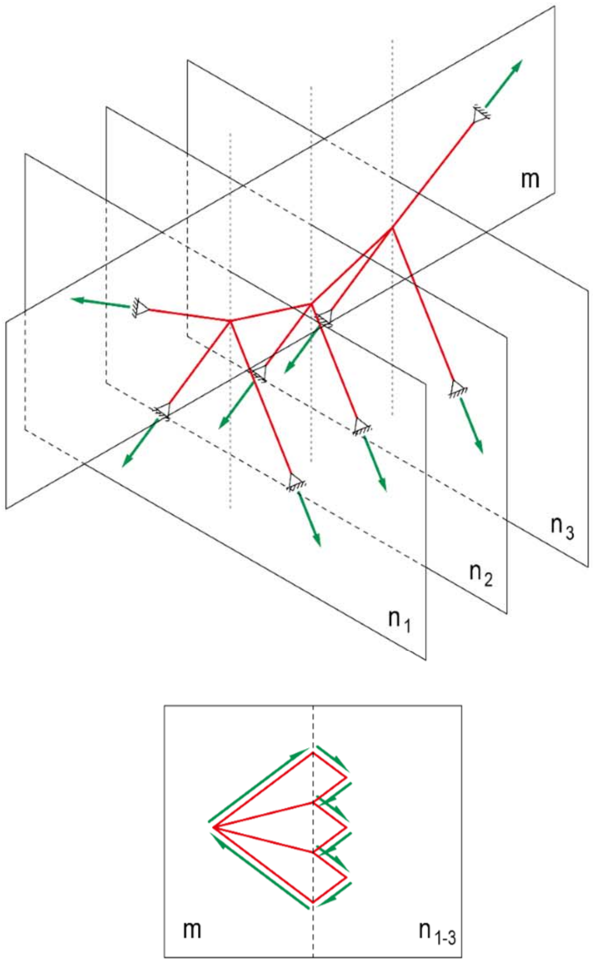

B
A
m
P
P
D
C
n
B
P
A
m
+
C
P
D
n
B
C
A
D
m
n

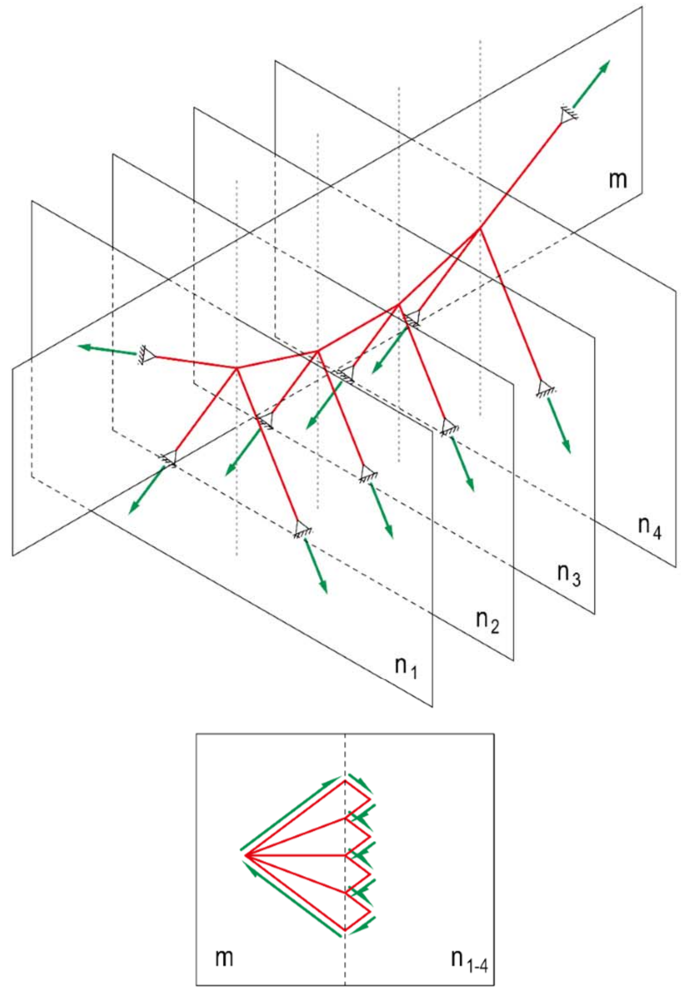

B
m
A
D
C
n

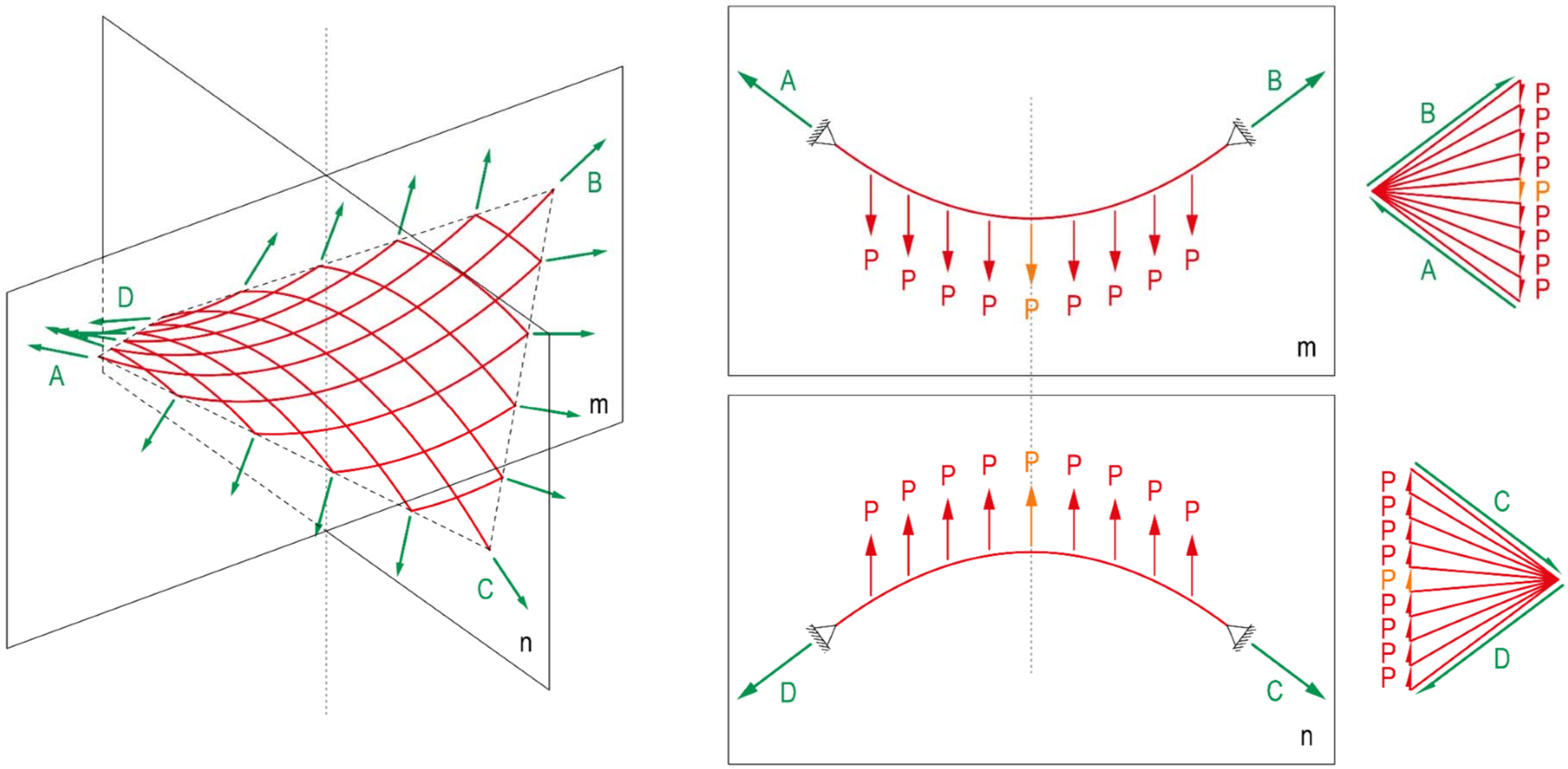

B
m
A
F
D
E
C
n2
n1


B
C
A
D
m
n


C
B
D
E
A
F
m
n1-2


m
n_3
n_2
n_1
m
n_{1-3}


m
n_4
n_3
n_2
n_1
m
n_{1-4}



B
D
A
m
C
n
A
B
P P P P P P P P P
m
B
P
P
P
P
P
P
P
P
P
A
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D
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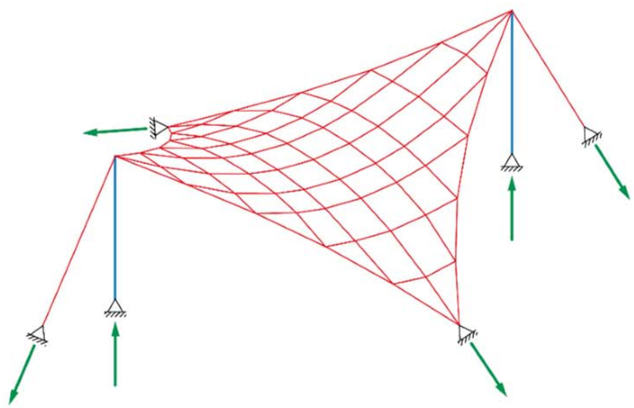
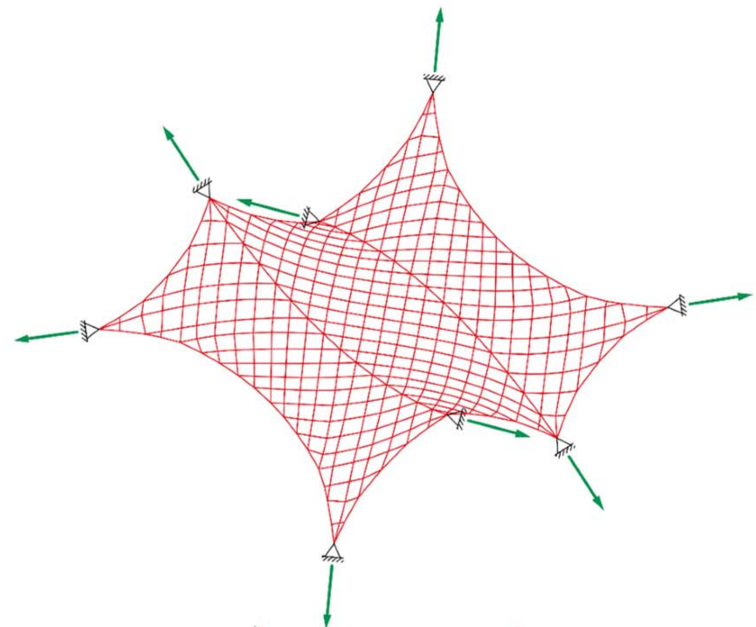
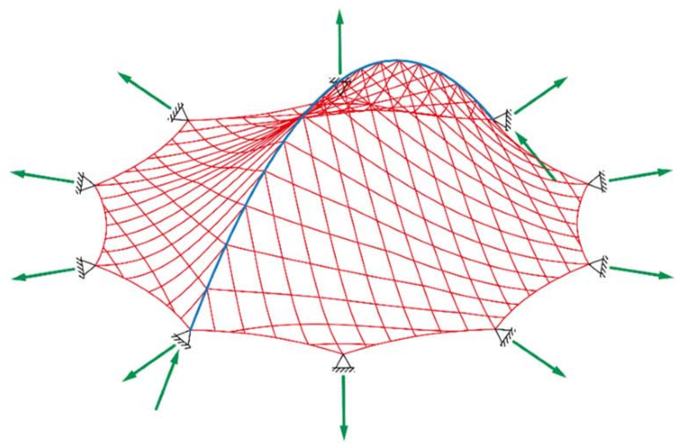
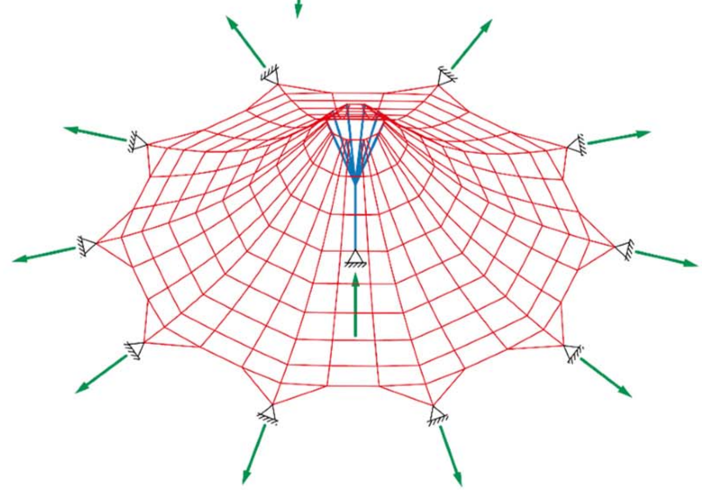
P
P
P
C
D









Frei Otto, German Pavilion, Montreal 1967

Günter Behnisch, Frei Otto, Olympiapark München, 1972

Structural Typologies

Cable structures

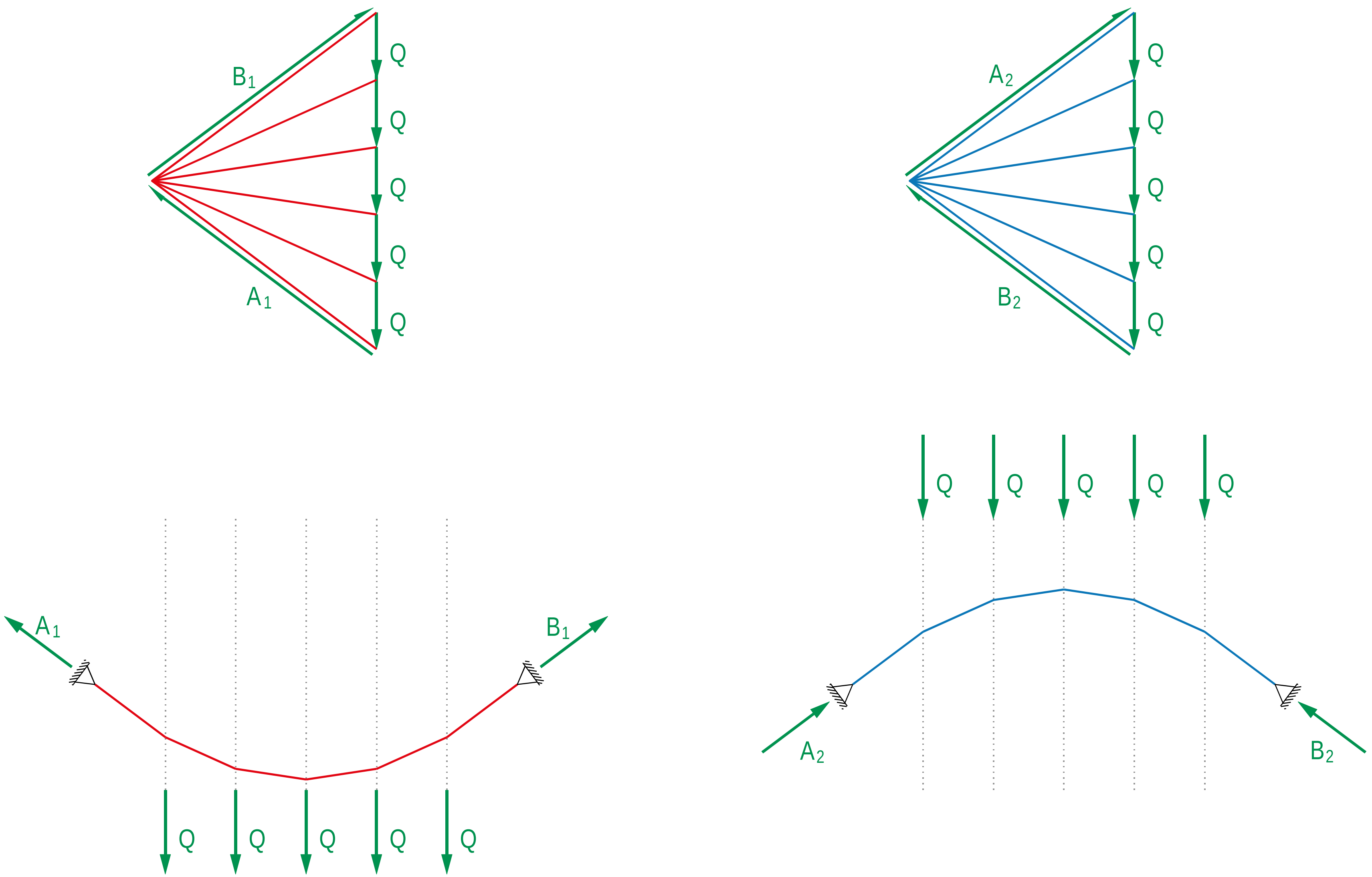
Arches and shells

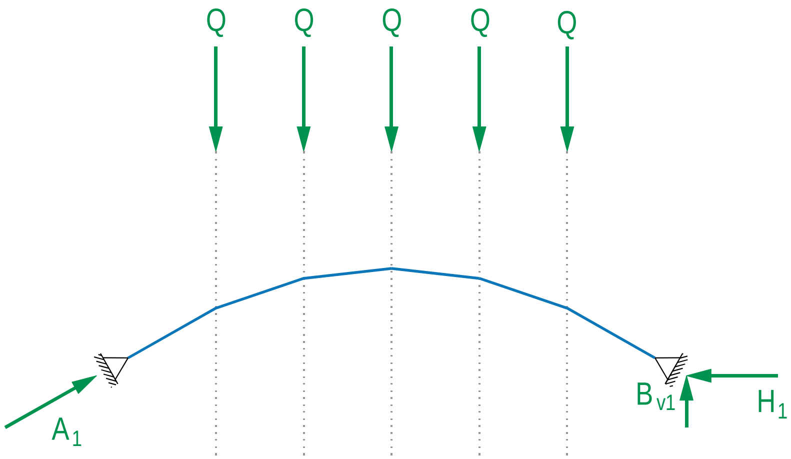
Arch-cable systems

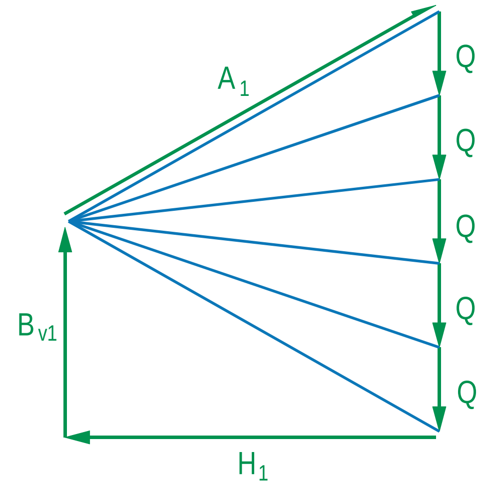
Trusses

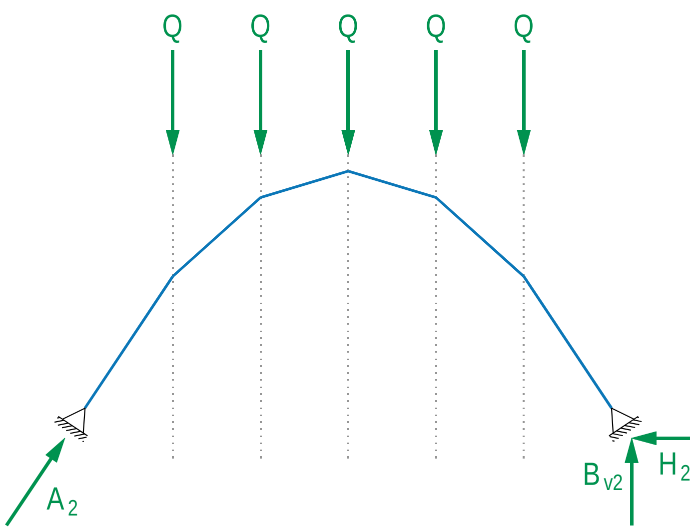
Beams

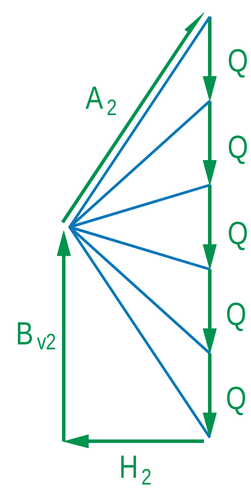
Frames


B_1
A_1
Q
Q
Q
Q
Q
A_2
B_2
Q
Q
Q
Q
Q
A_1
B_1
Q
Q
Q
Q
Q
Q
Q
Q
Q
Q
A_2
B_2

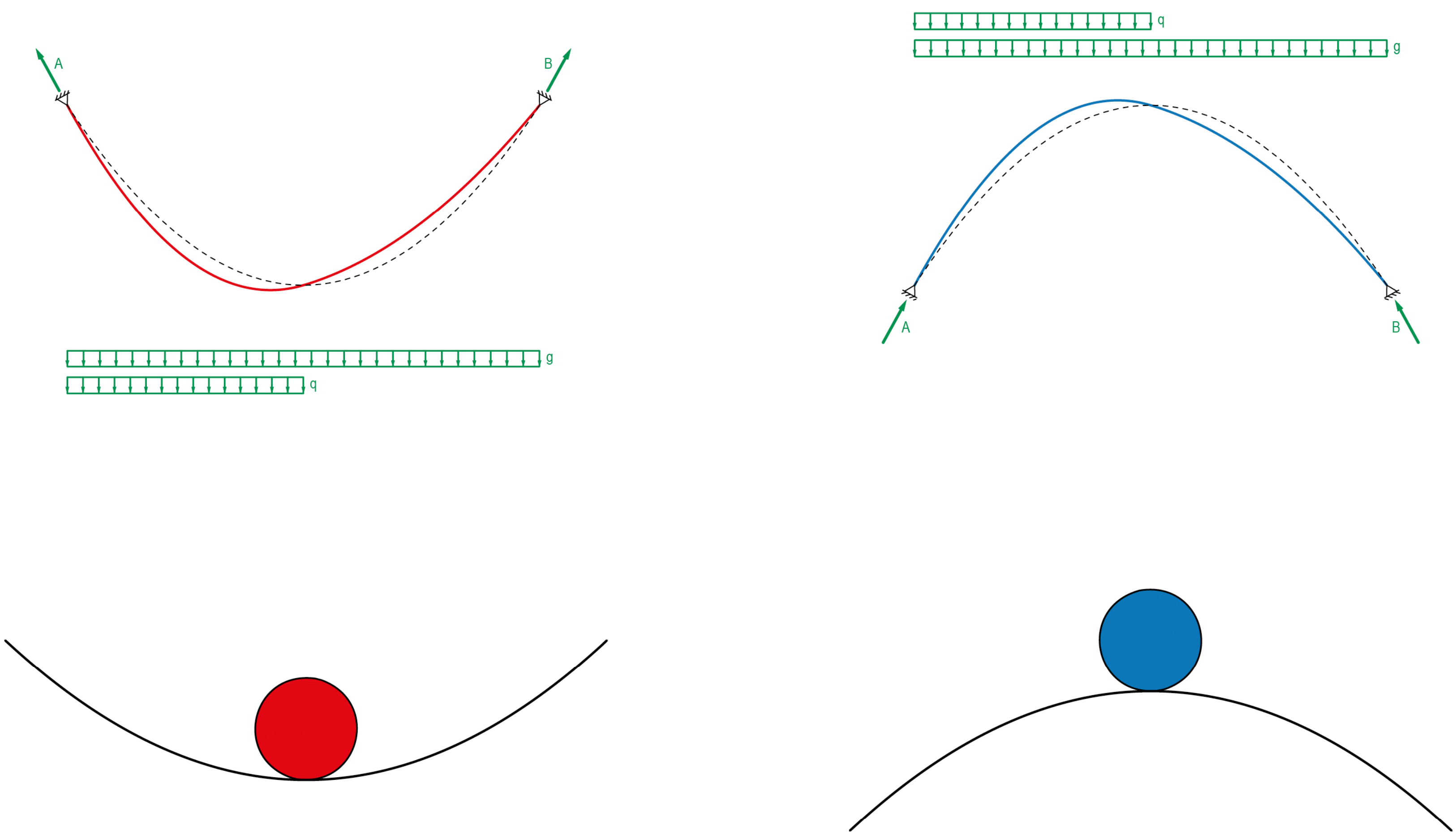

Q
Q
Q
Q
Q
A_1
B_{v1}
H_1


A_1
Q
Q
Q
Q
Q
B_{v1}
H_1

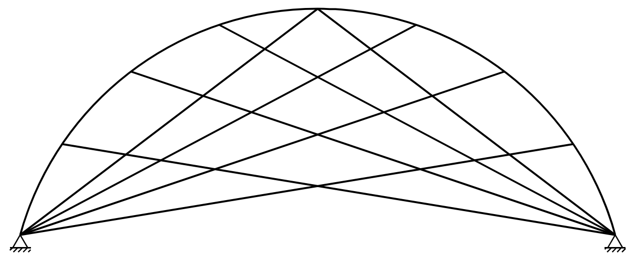

Q
Q
Q
Q
Q
A_2
B_{v2}
H_2


A_2
Q
Q
Q
Q
Q
B_{v2}
H_2

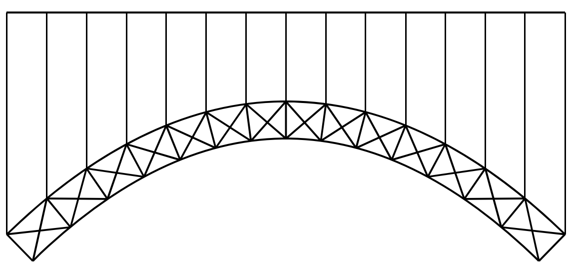
Gateway Arch, Eero Saarinen, St. Louis, 1965



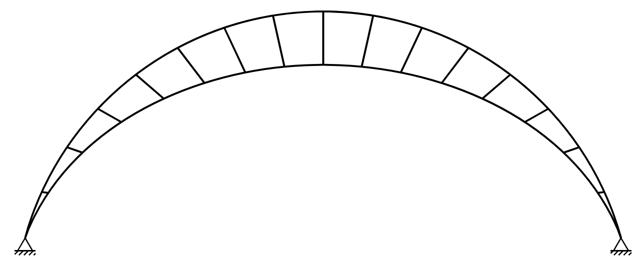
Different behaviour of cables and arches for changing live loads



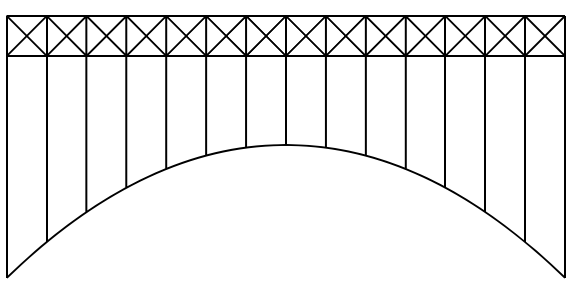
Prestress



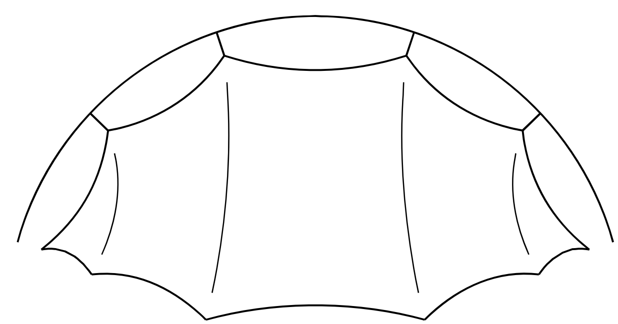
Stiffness of the arch



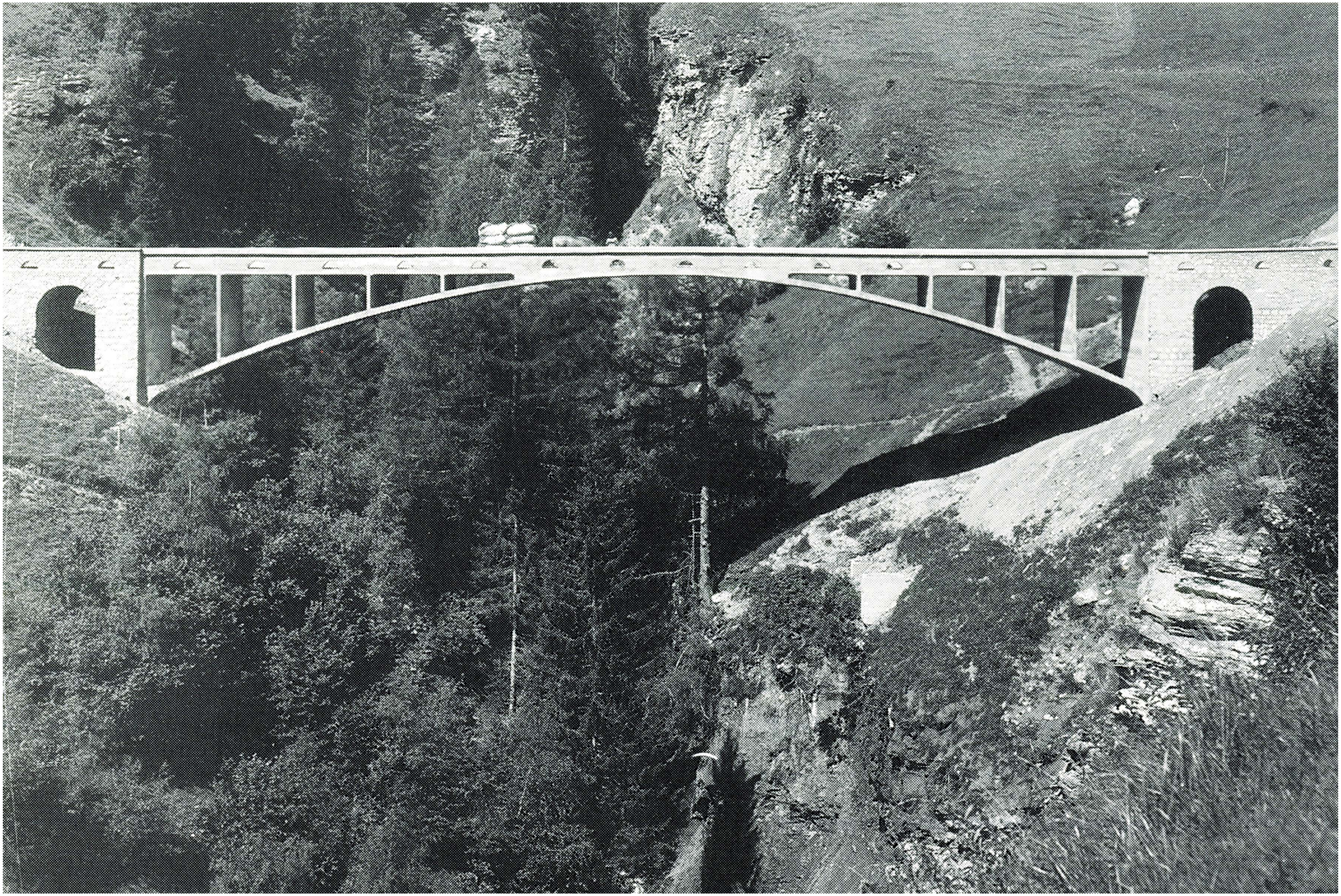
Planar tension stiffening



Stiffness of the beam



Spatial cable net/membrane

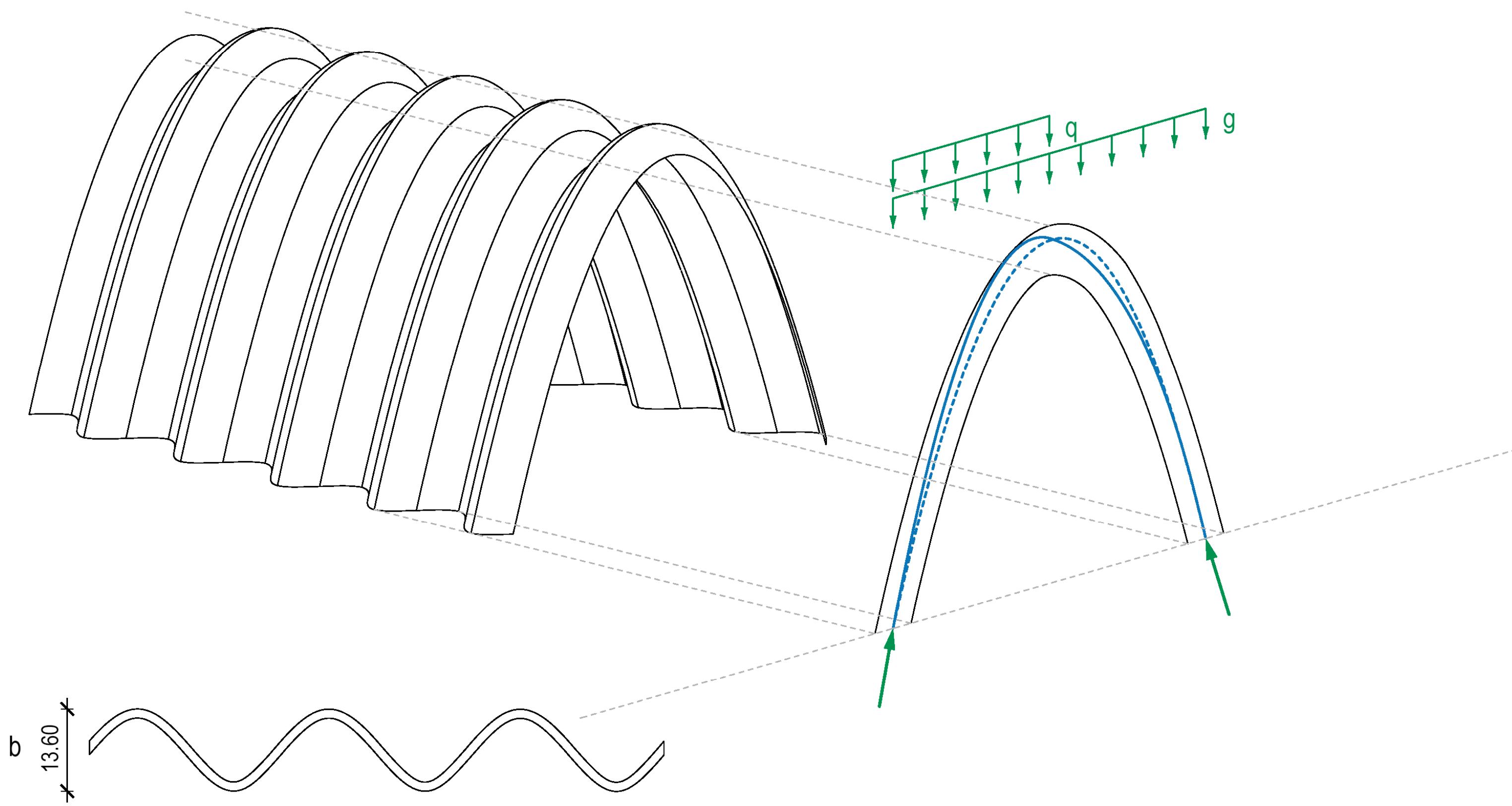


Robert Maillart: Valtschielbachbridge, Donath, 1925

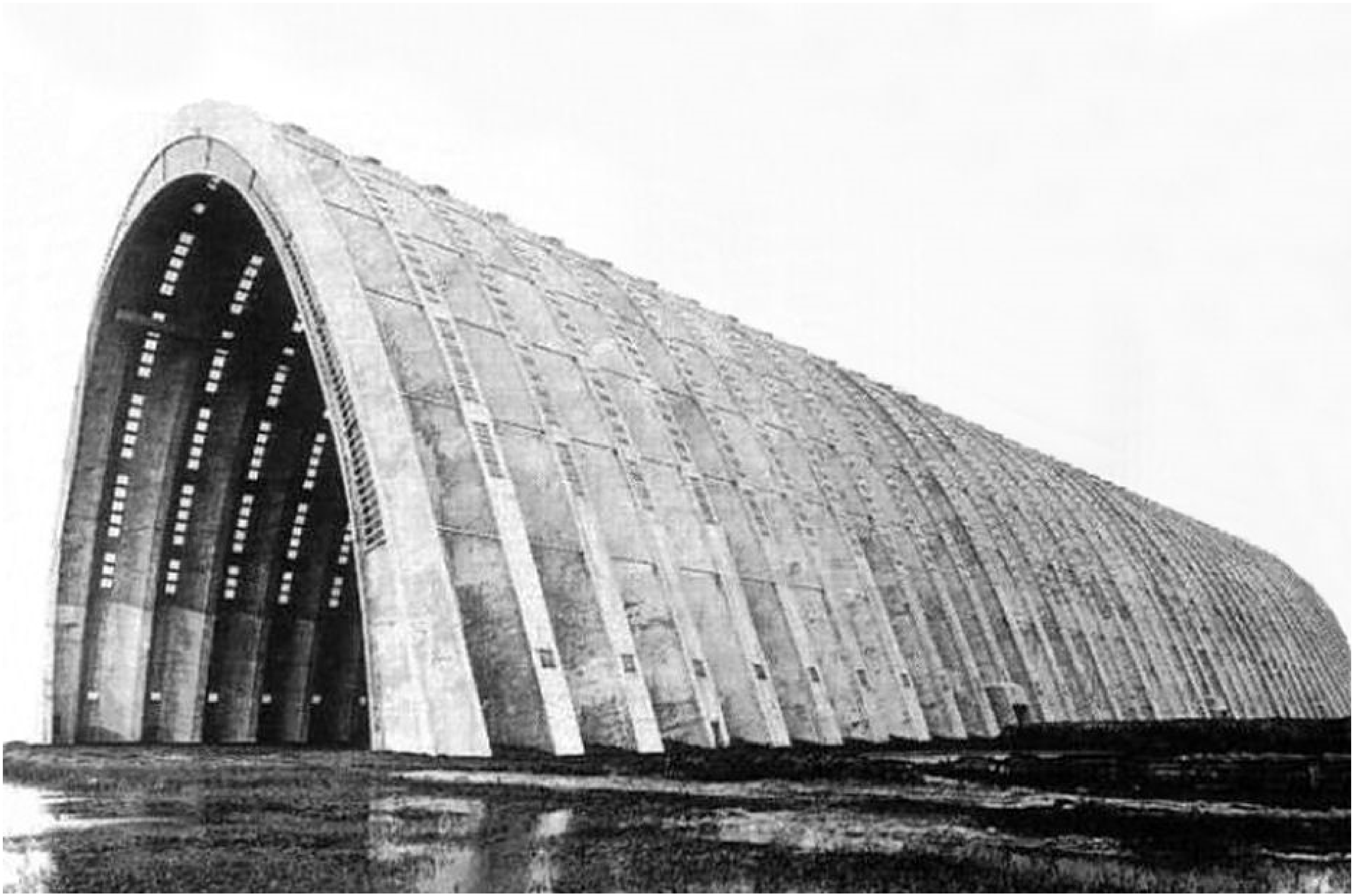
Robert Maillart: Salginatobelbridge, Schiers, 1930

A Pomerantsev, V. Shukhov: State warehouse GUM, Moscow, 1893

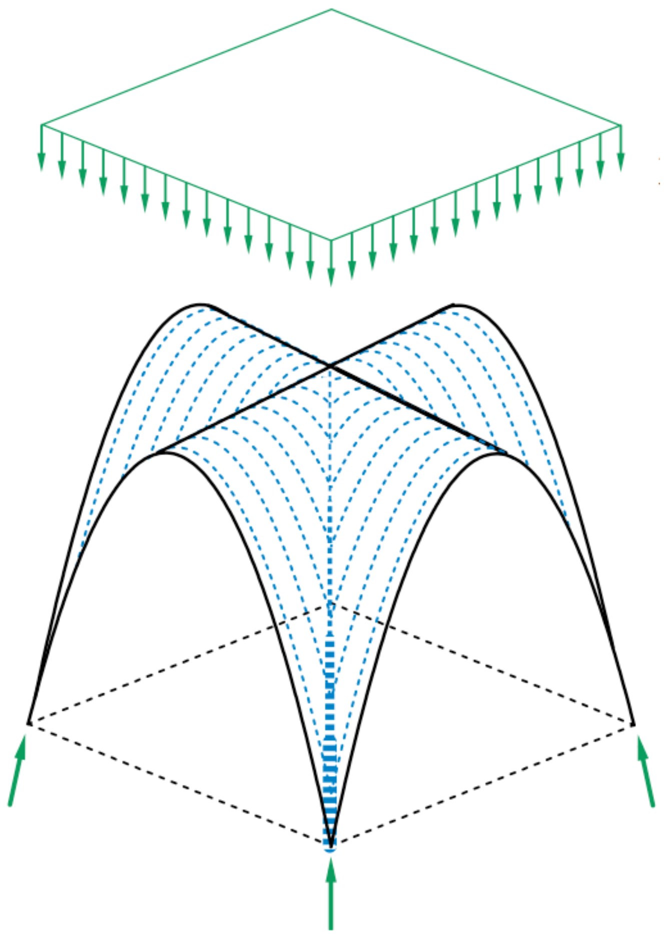
R. Brosi & Obrist and Partner, Peter Rice: Bus station Chur, 1992

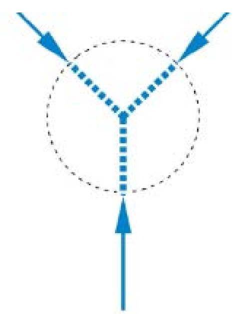

q
g
b
13.60

Eladio Dieste: Cadyl Horizontal Silo, Young, Uruguay, 1978



Eugène Freyssinet: Hangars of the Orly Airport, France, 1923





New Norcia Cathedral in Perth, Arch.: P.L. Nervi, F. Vecchini & C. Vannoni

Structural Typologies

Cable structures

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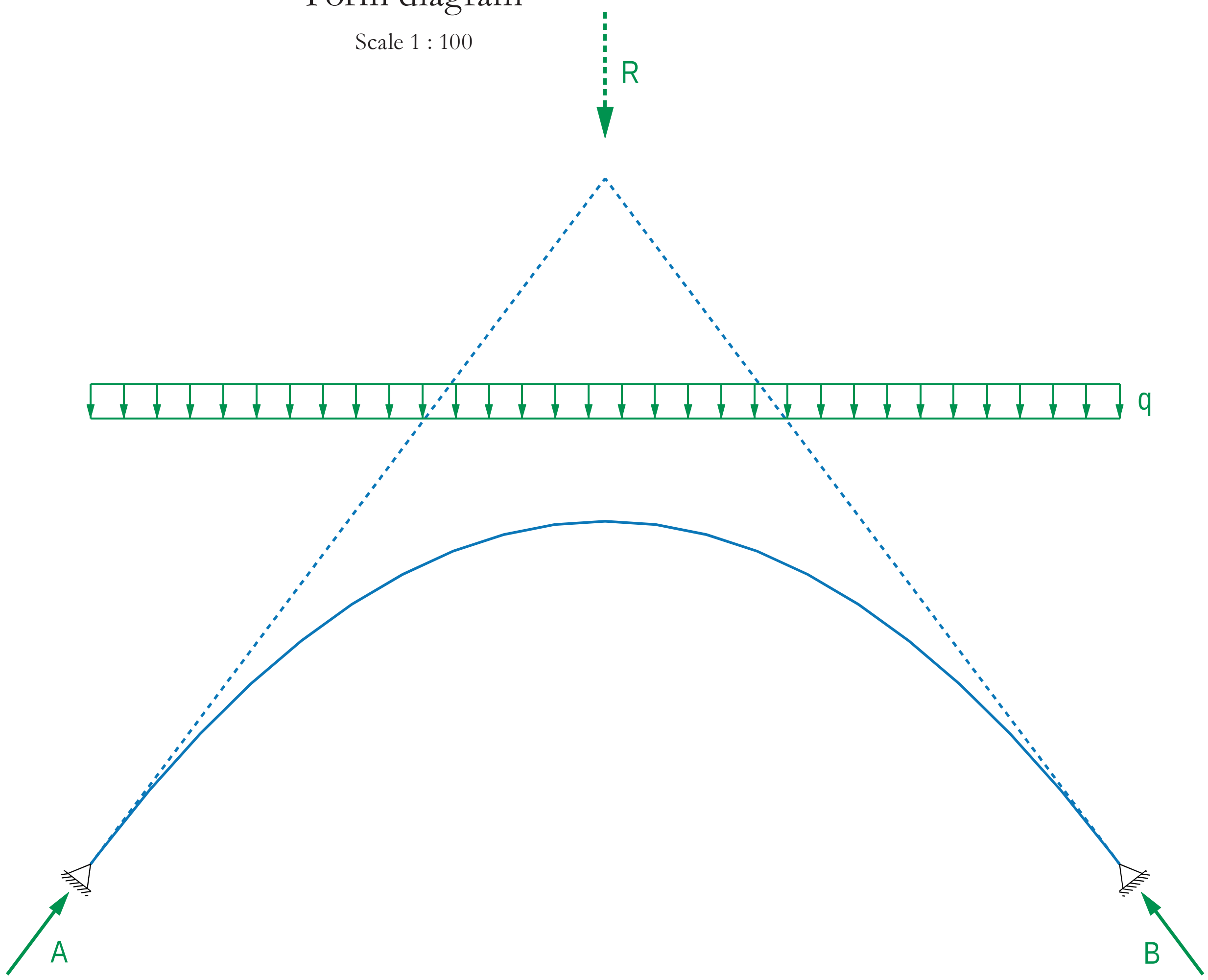
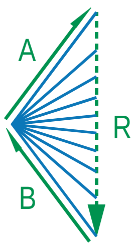
Form diagram

Scale 1 : 100



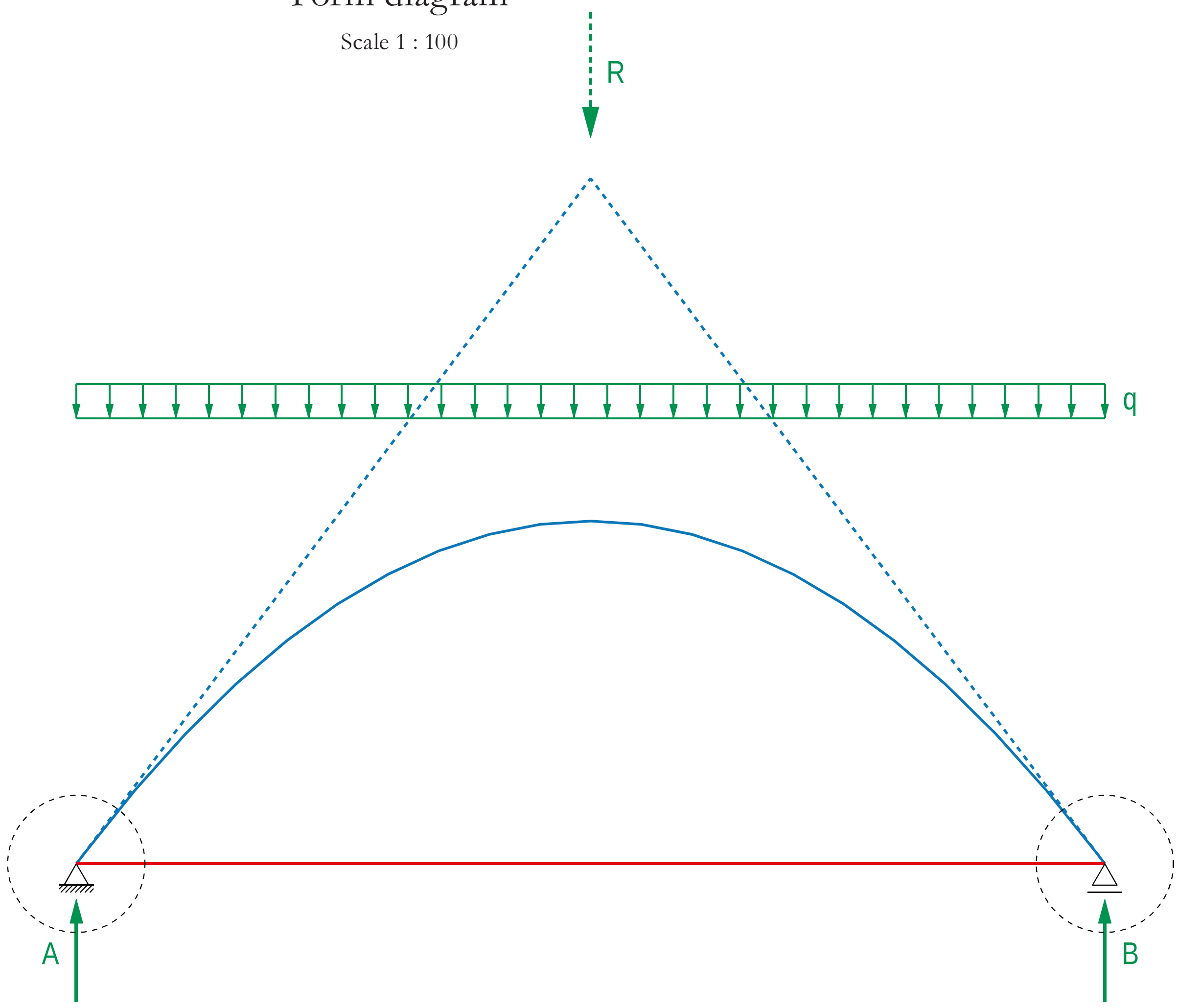
Force diagram

Scale 1 cm ≙ 1 kN



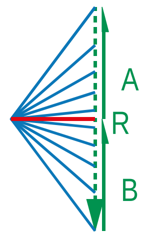
Form diagram

Scale 1 : 100



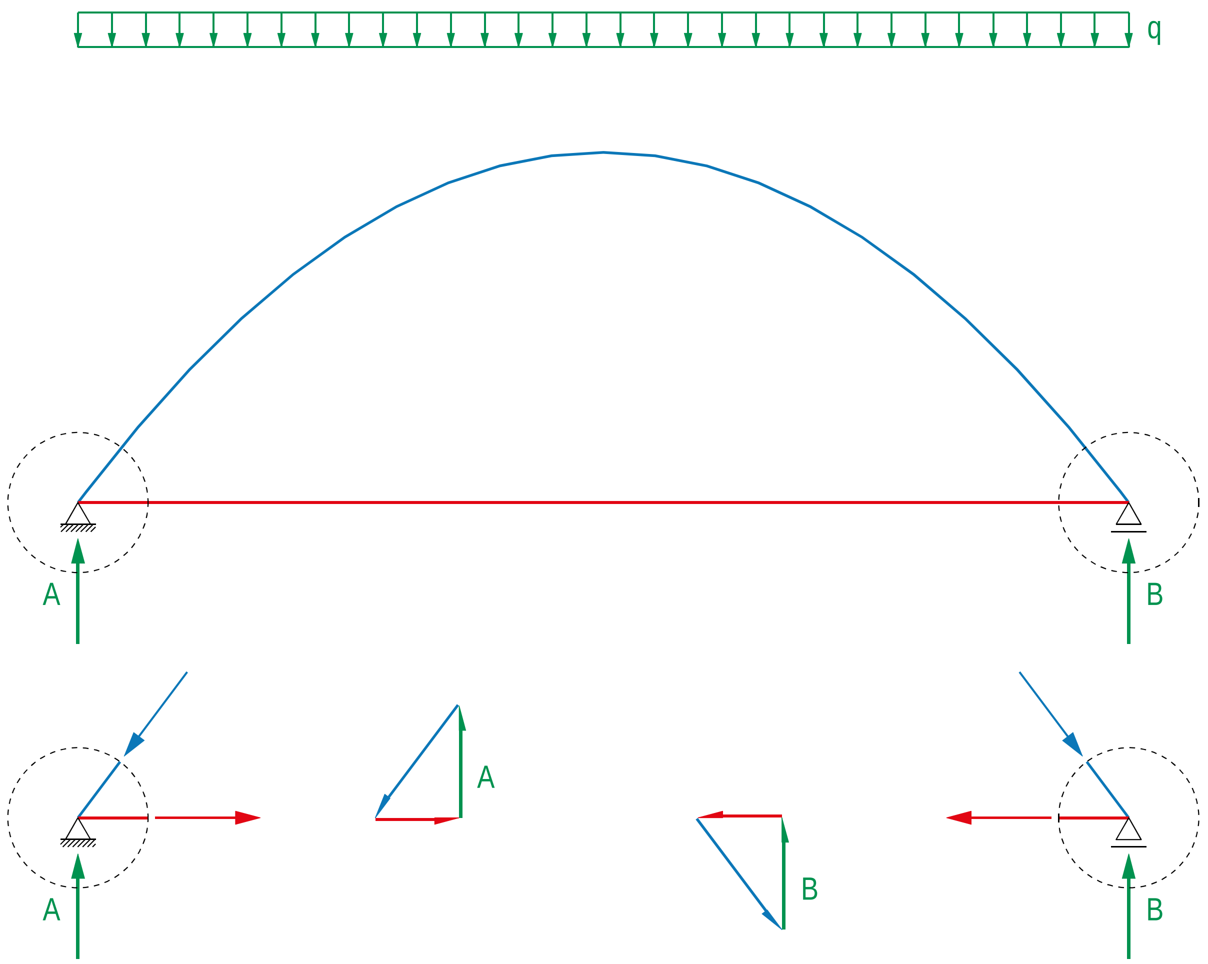
Force diagram

Scale 1 cm ≙ 1 kN



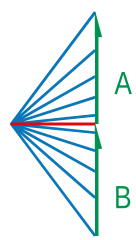
Form diagram

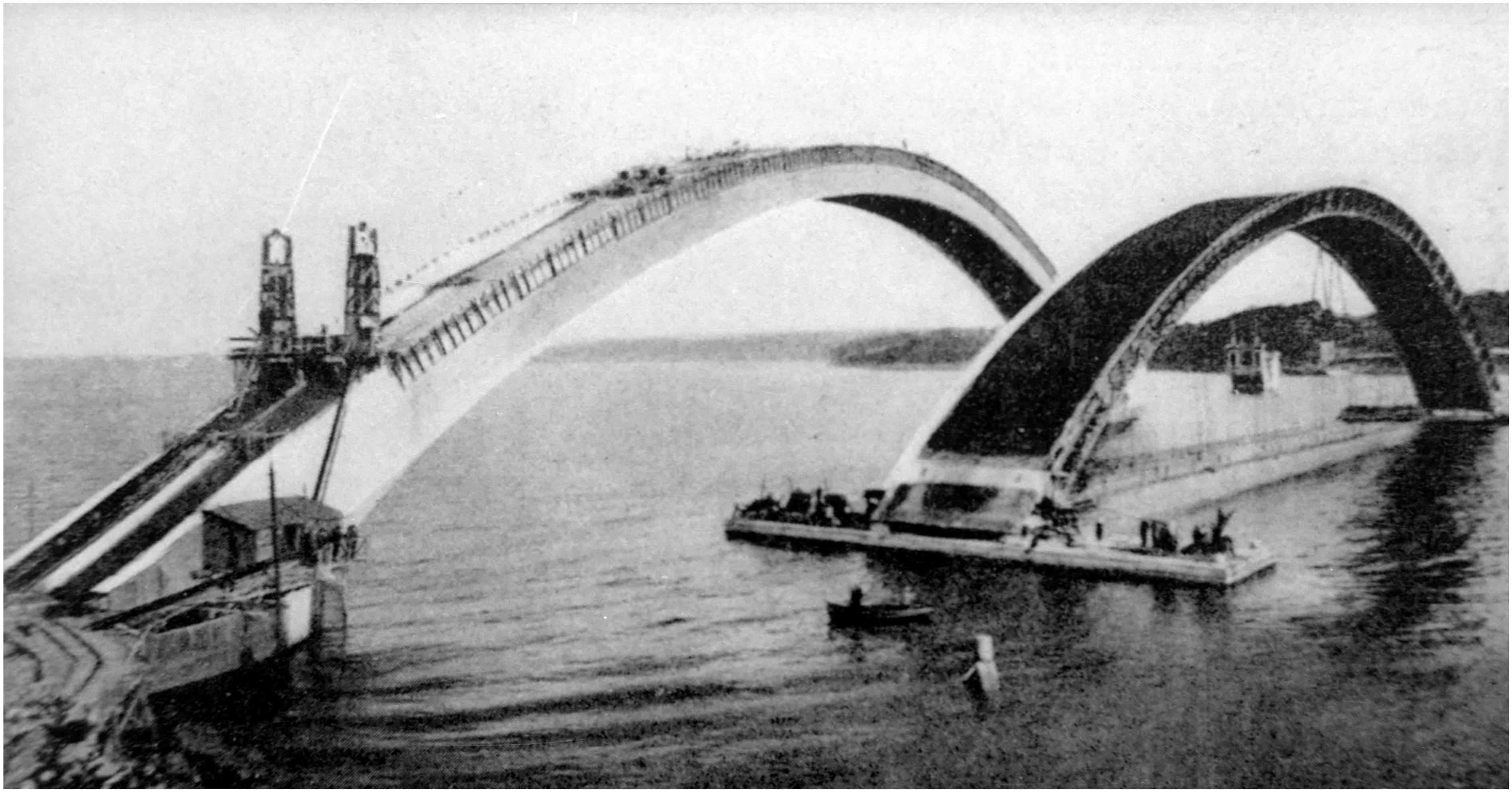
Scale 1 : 100



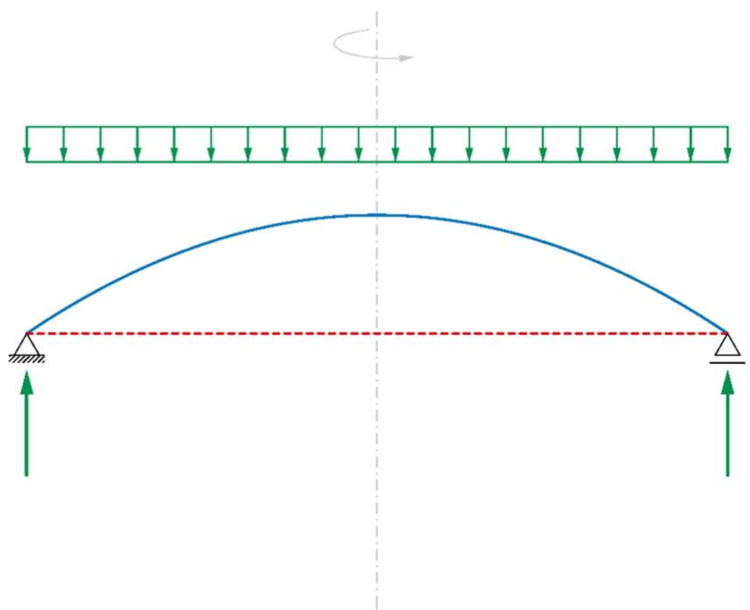
Force diagram

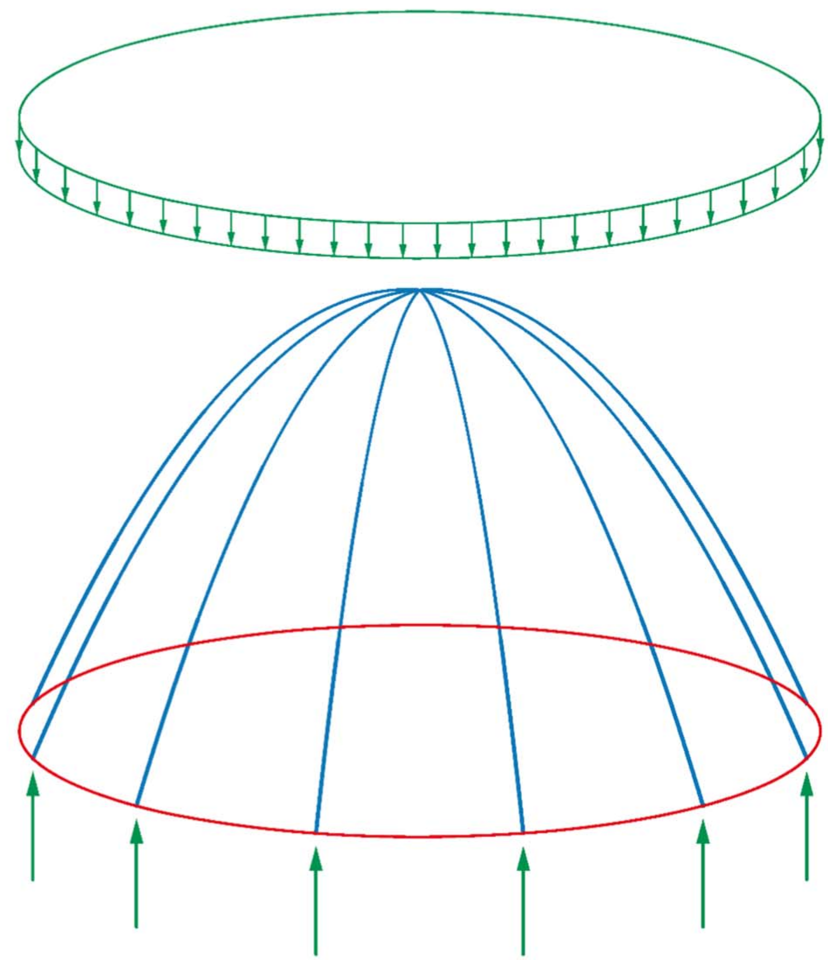
Scale 1 cm ≙ 1 kN

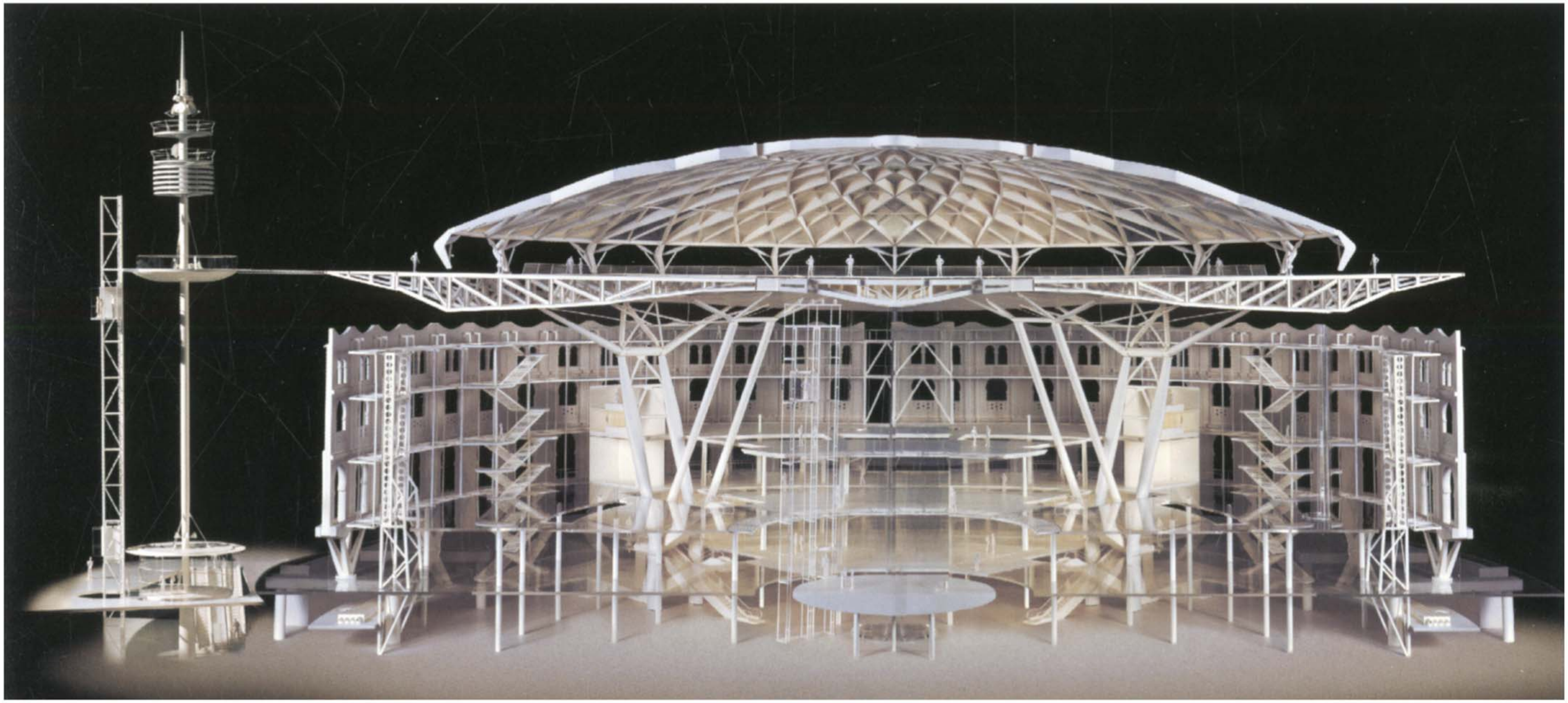




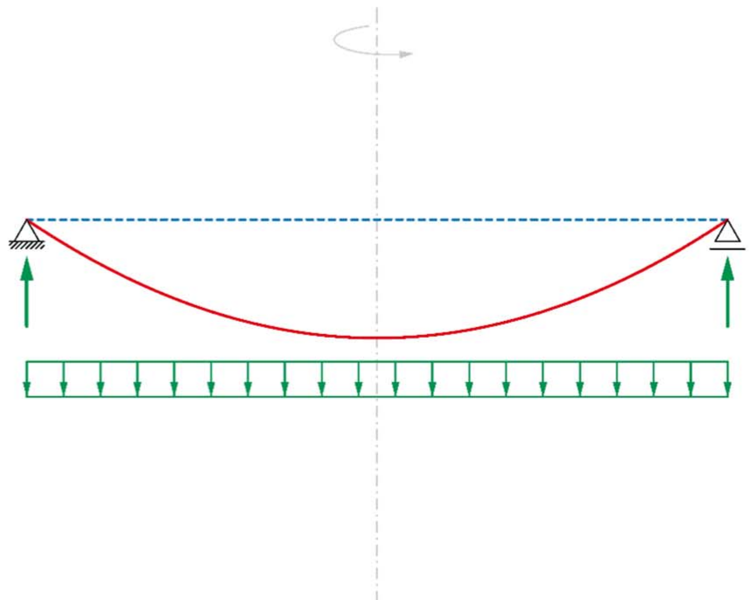
Eugène Freyssinet: Pont Albert Louppe, Bretagne, 1930

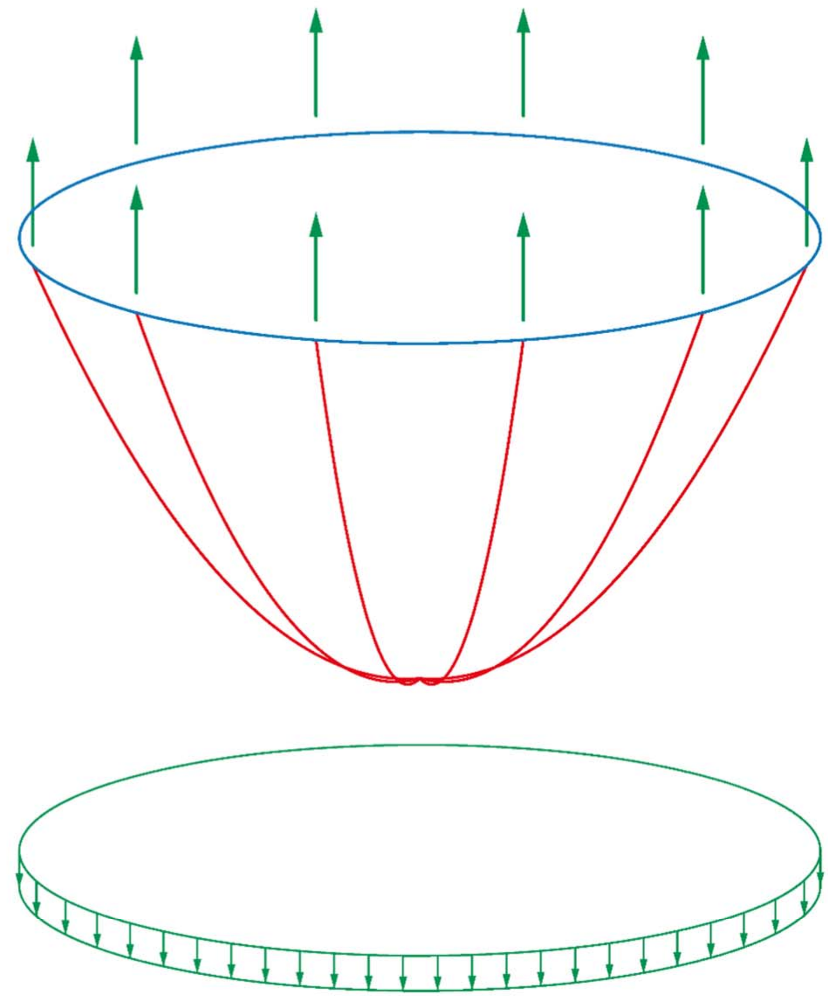


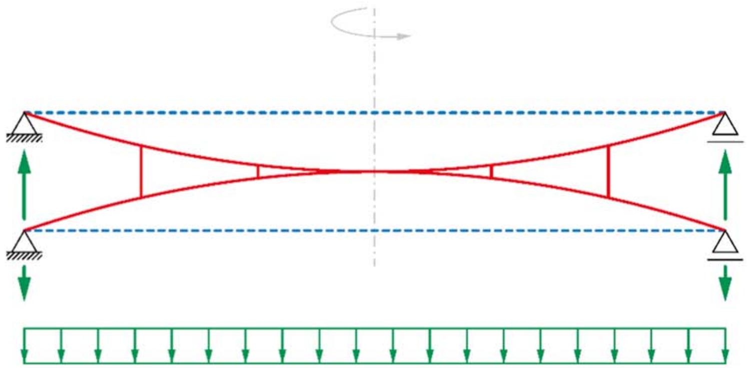


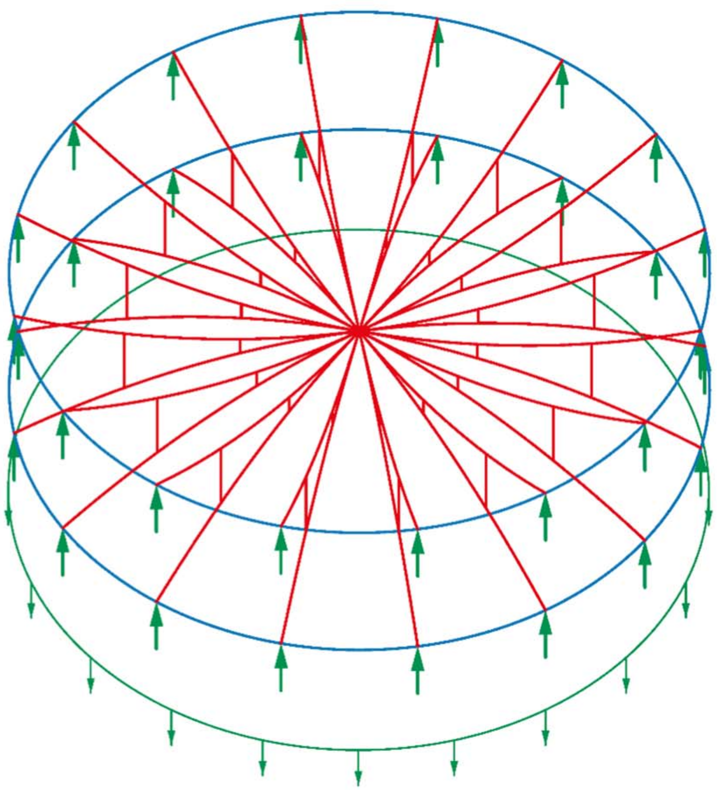


R. Rogers: Las Arenas, Barcelona, 2009

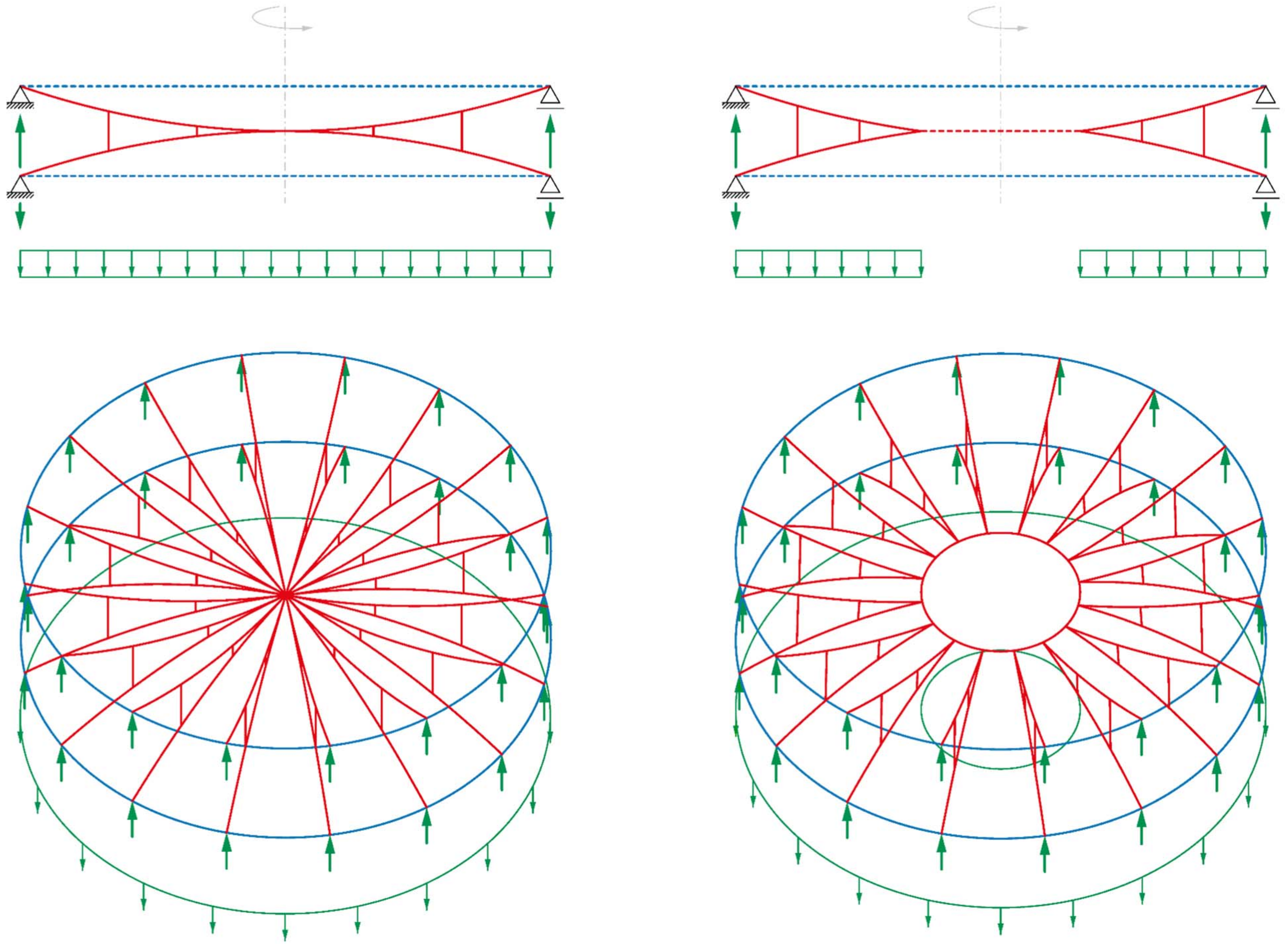




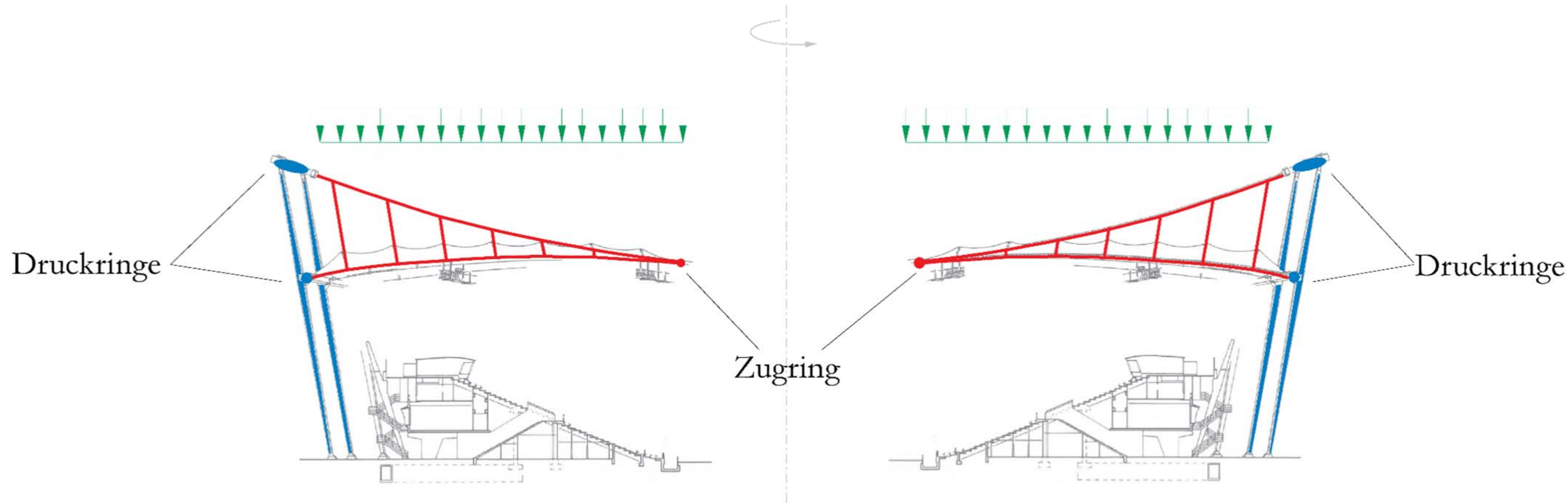




Aussteifungskonzepte



Asp Architekten, Schlaich Bergermann & Partner: Mercedes Benz Arena, Stuttgart, 1993

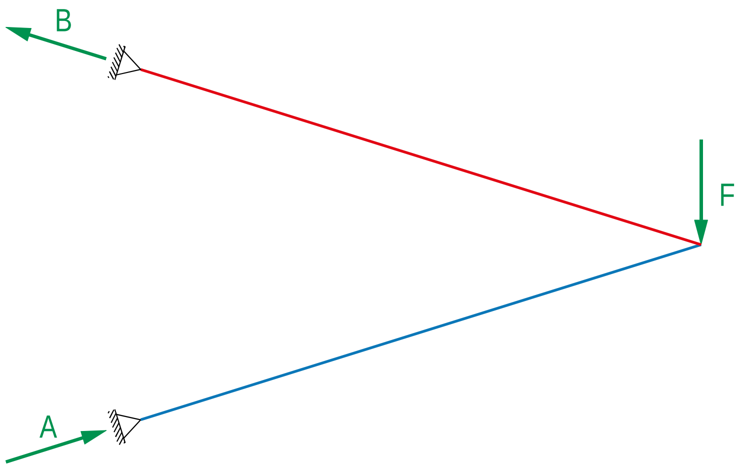


Asp Architekten, Schlaich Bergermann & Partner: Mercedes Benz Arena, Stuttgart, 1993

Asp Architekten, Schlaich Bergermann & Partner: Mercedes Benz Arena, Stuttgart, 1993

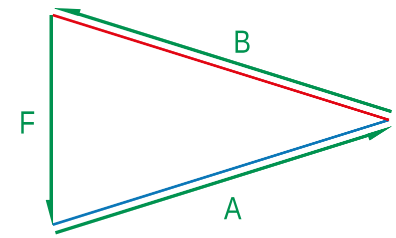
Form diagram

Scale 1 : 100



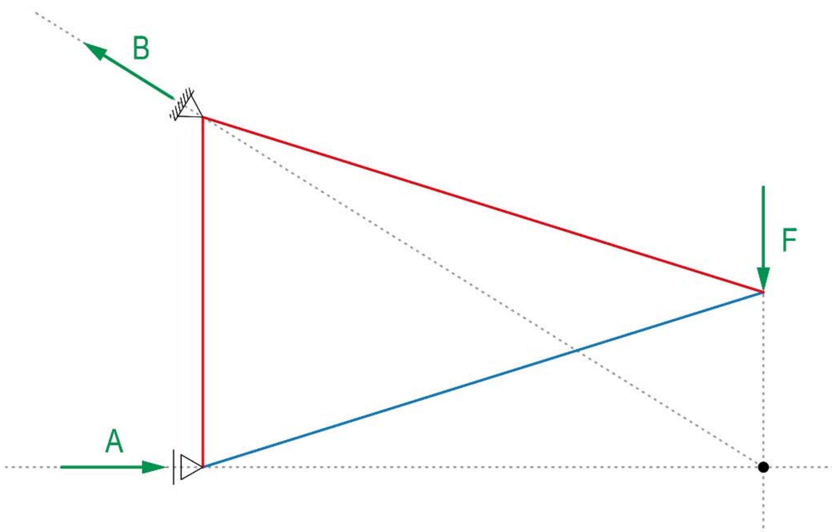
Force diagram

Scale 1 cm ≙ 1 kN



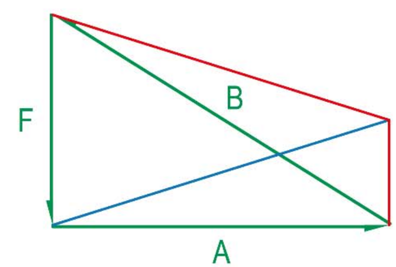
Form diagram

Scale 1 : 100



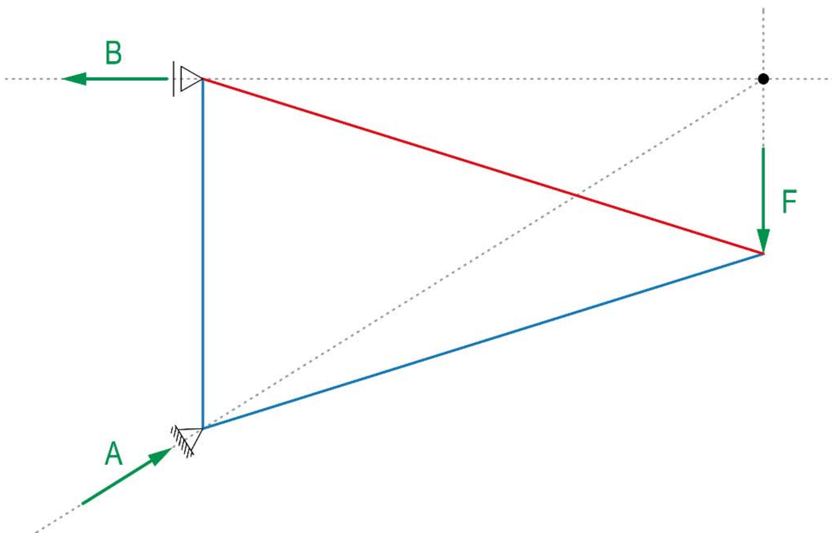
Force diagram

Scale 1 cm ≙ 1 kN



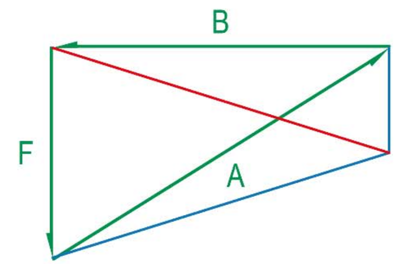
Form diagram

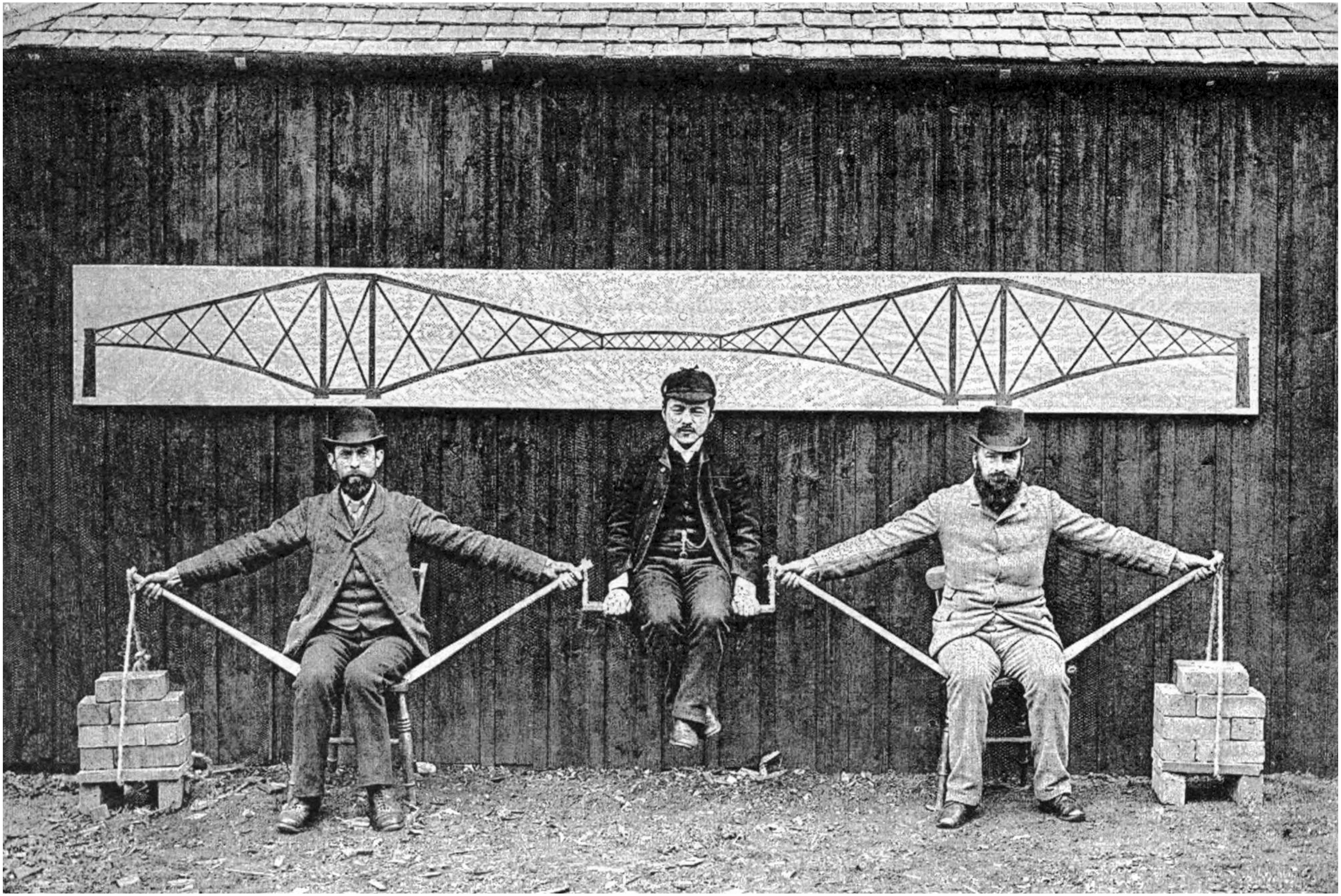
Scale 1 : 100



Force diagram

Scale 1 cm ≙ 1 kN

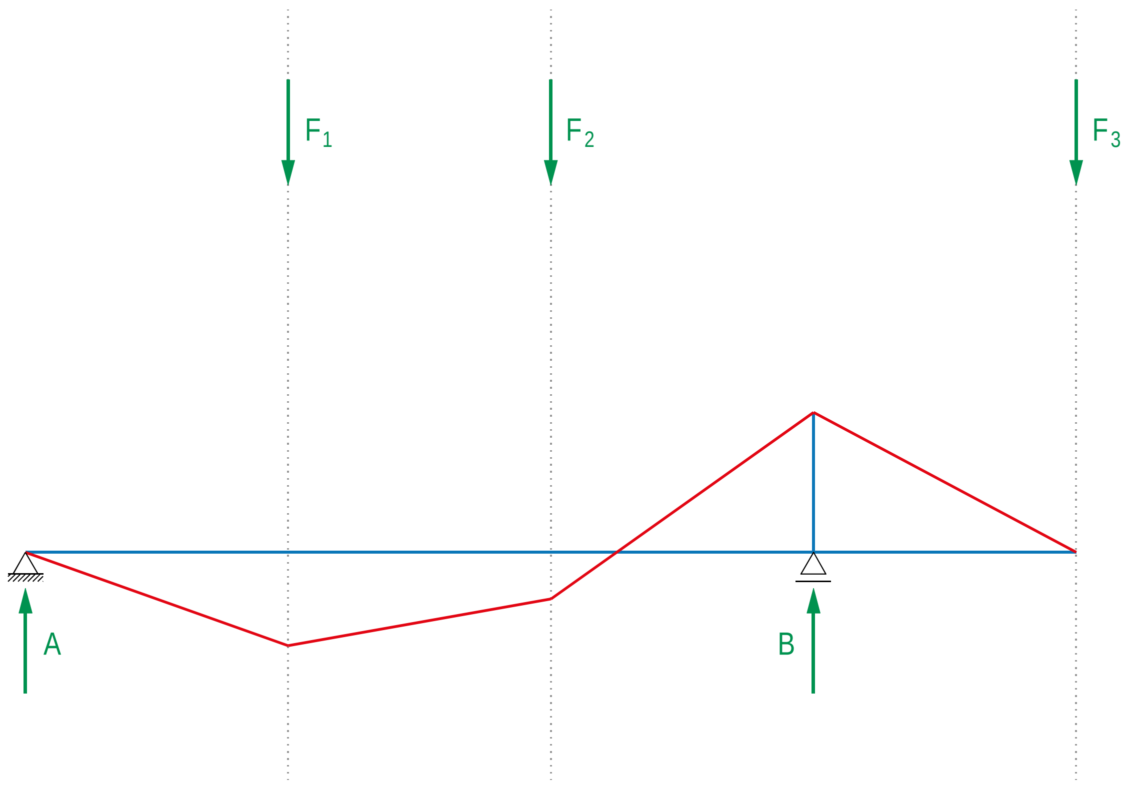




Sir John Fowler, Sir Benjamin Baker: Forth Bridge, South Quennsferry, 1890

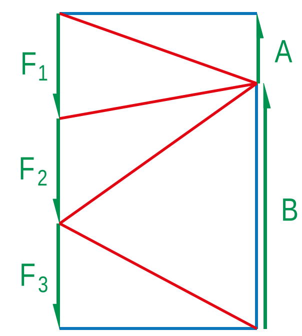
Form diagram

Scale 1 : 100



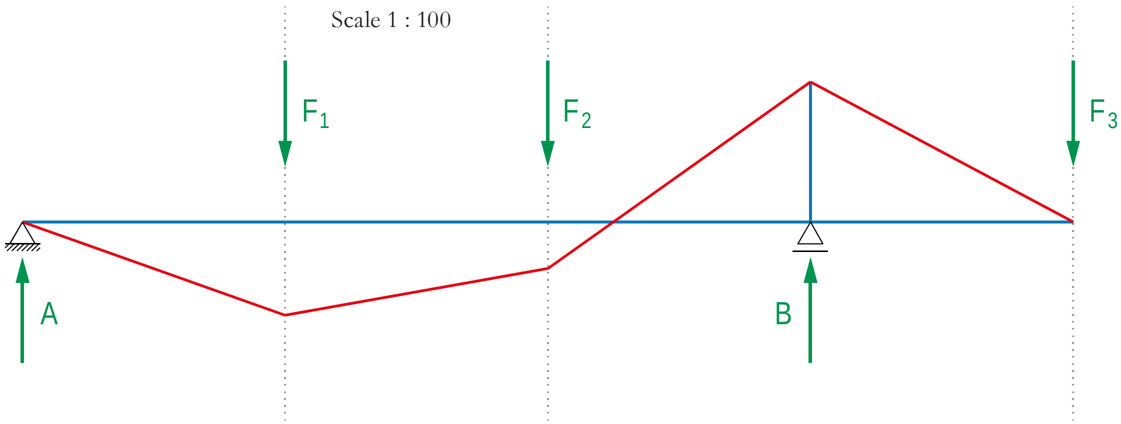
Force diagram

Scale 1 cm ≙ 1 kN



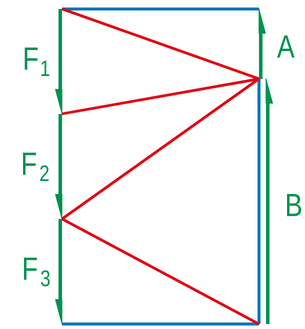
Form diagram

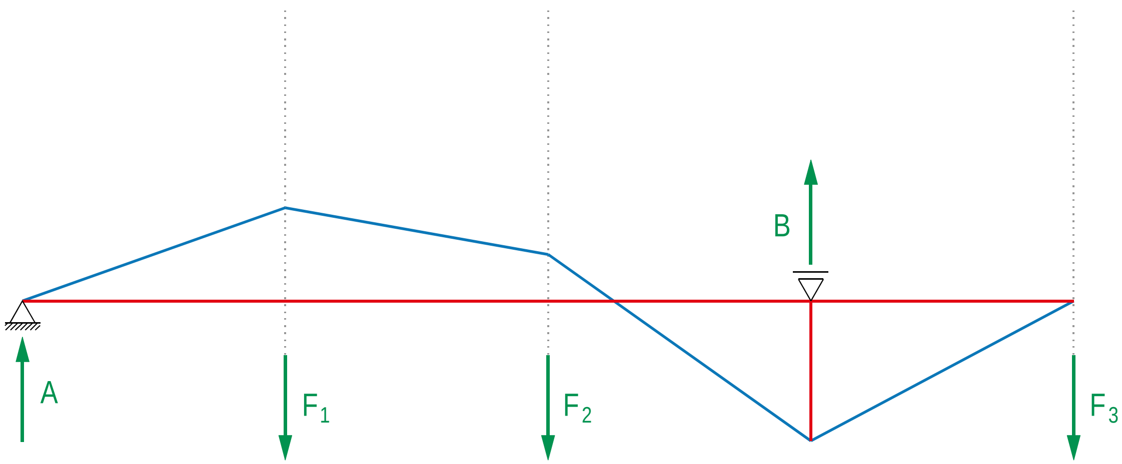
Scale 1 : 100

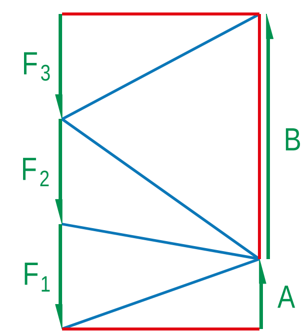


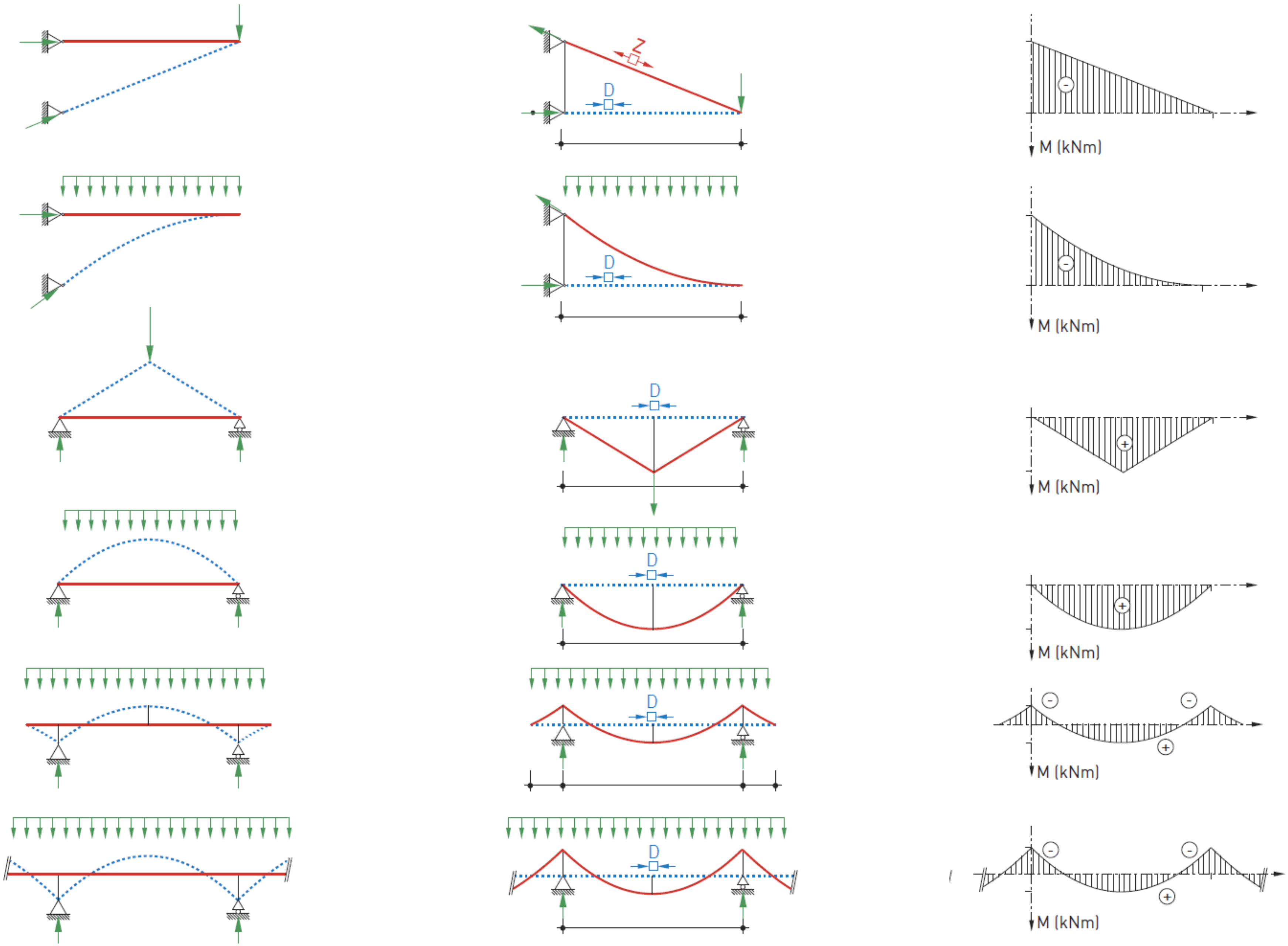
Force diagram

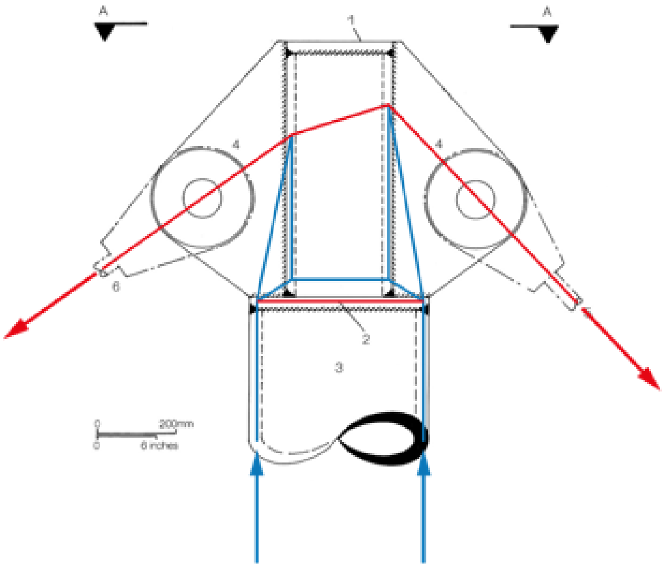
Scale 1 cm ≙ 1 kN

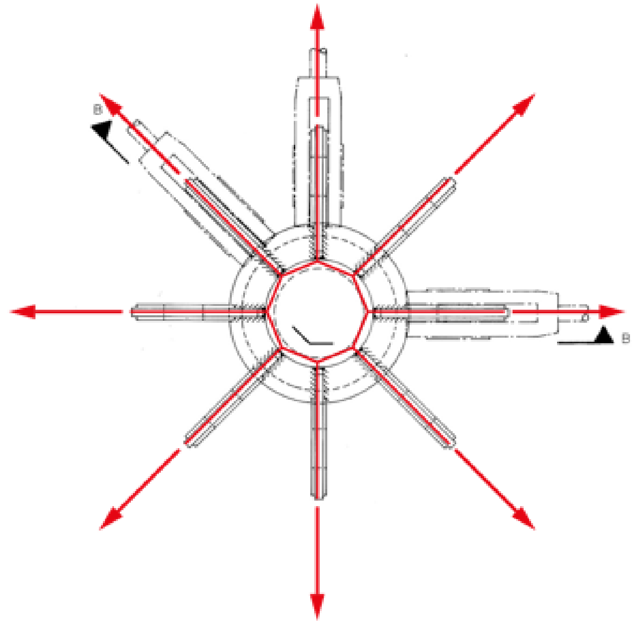




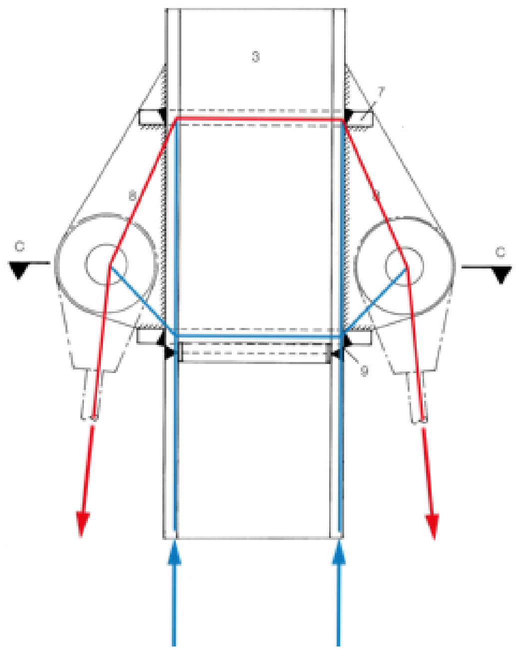


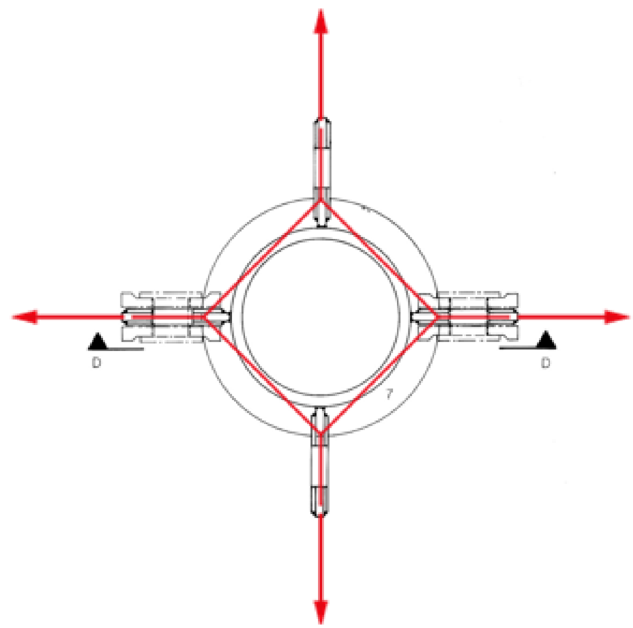

Z
D
M (kNm)
D
M (kNm)
D
M (kNm)
D
M (kNm)
D
M (kNm)
D
M (kNm)


A
A
1
4
4
6
2
3
0
200mm
0
6 inches


B
B


© Dennis Gilbert


3
7
C
C
9


D
D
7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Structural Typologies

Cable structures

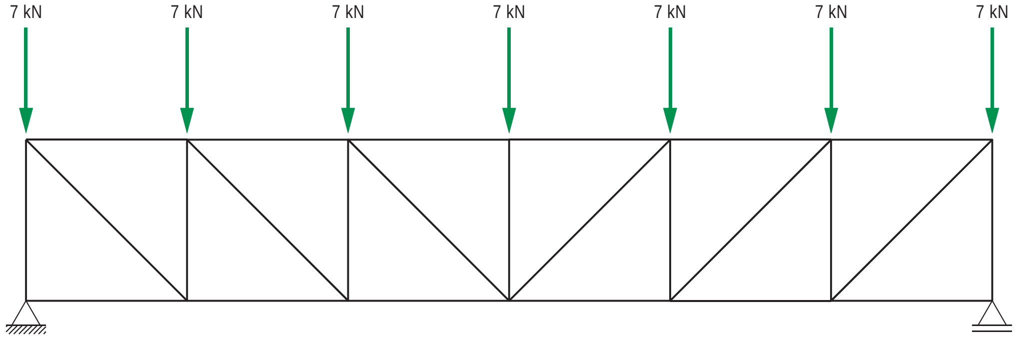
Arches and shells

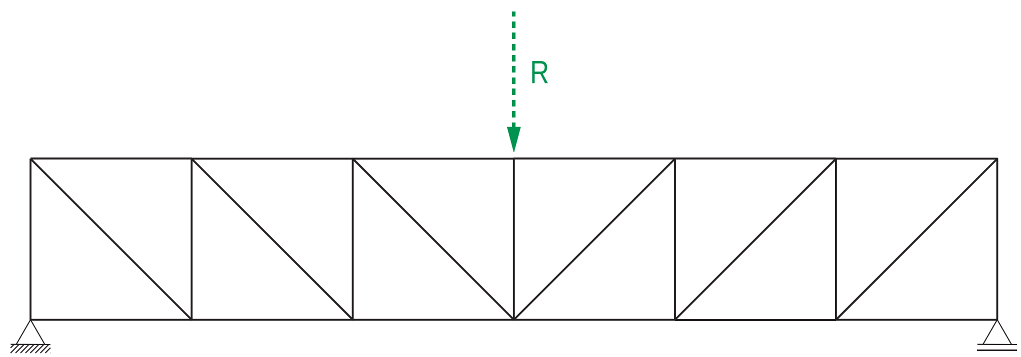
Arch-cable systems

Trusses

Beams

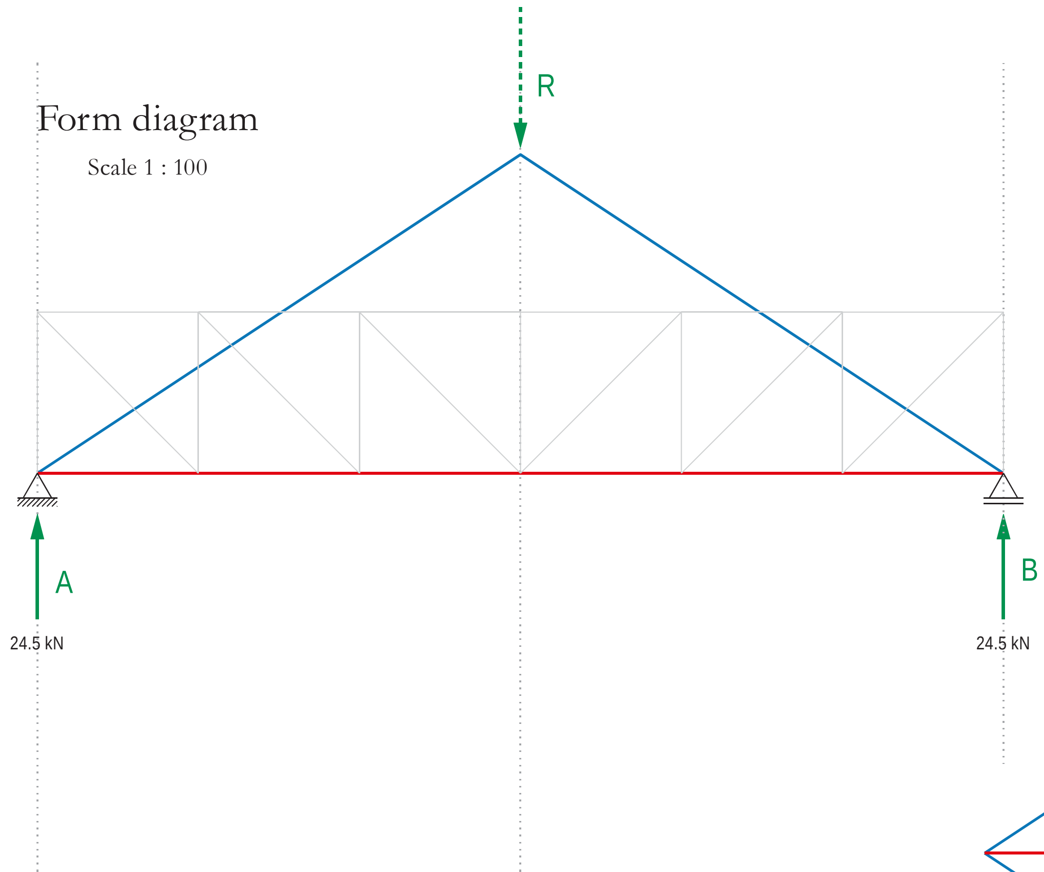
Frames


7 kN
7 kN
7 kN
7 kN
7 kN
7 kN
7 kN


R

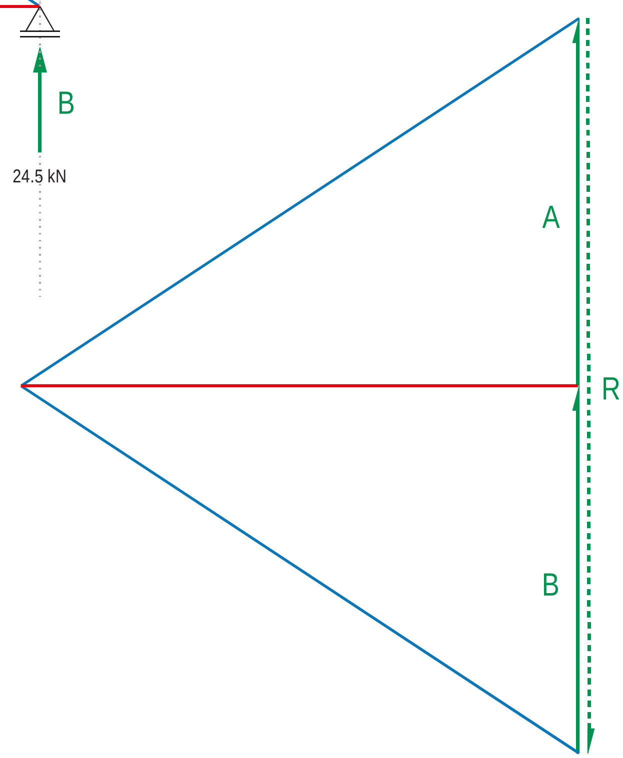
Form diagram

Scale 1 : 100



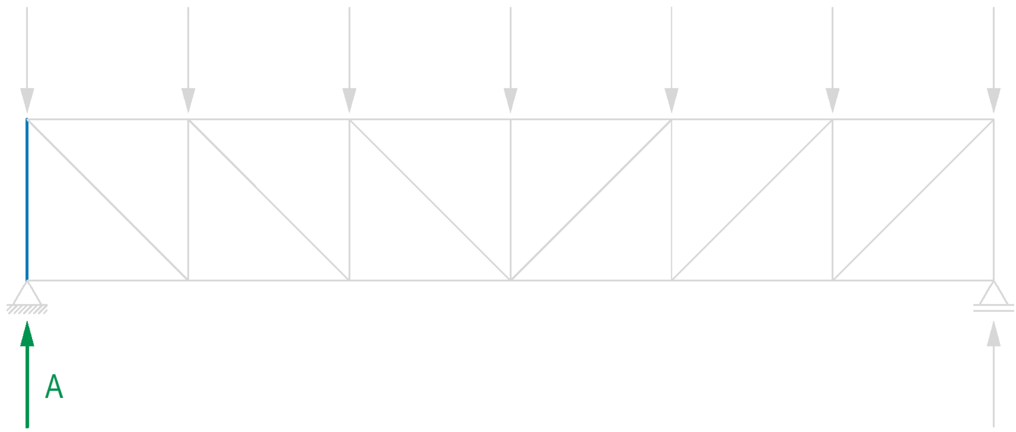
Force diagram

Scale 1 cm ≙ 1 kN



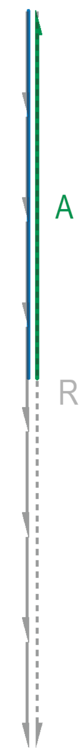
Form diagram

Scale 1 : 100



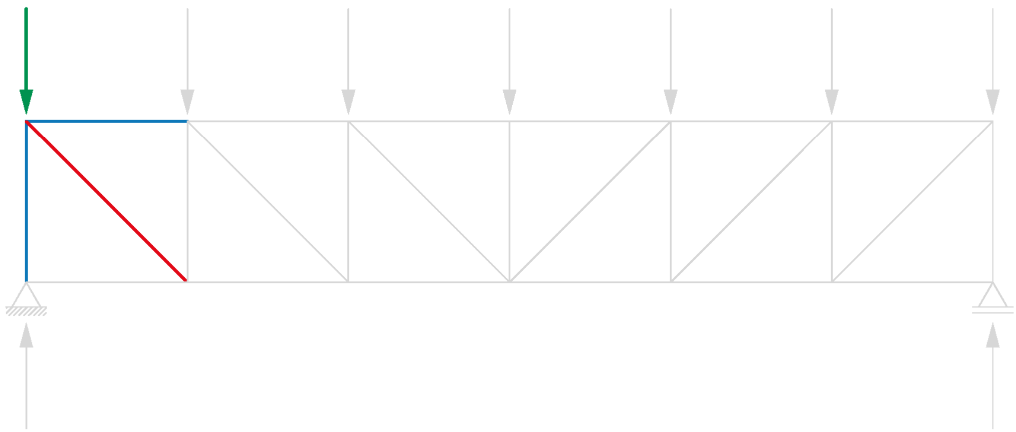
Force diagram

Scale 1 cm ≙ 1 kN



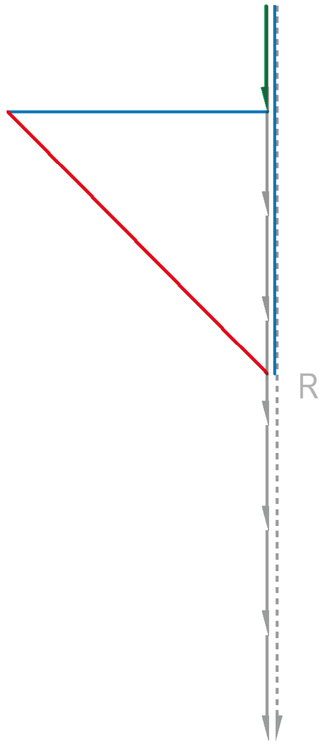
Form diagram

Scale 1 : 100



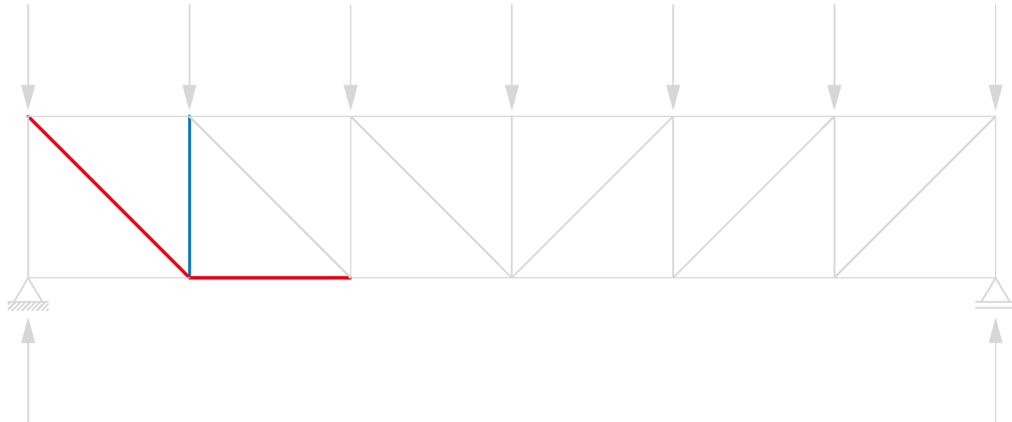
Force diagram

Scale 1 cm ≙ 1 kN



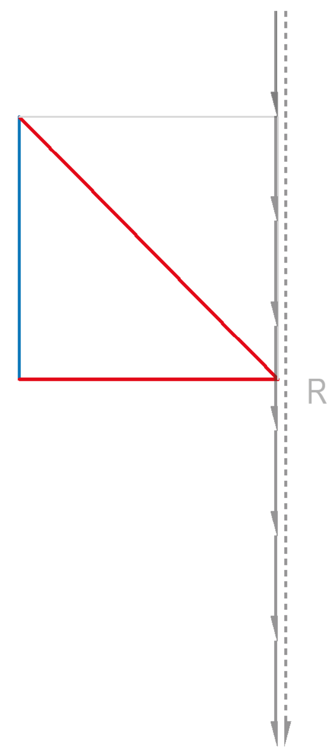
Form diagram

Scale 1 : 100



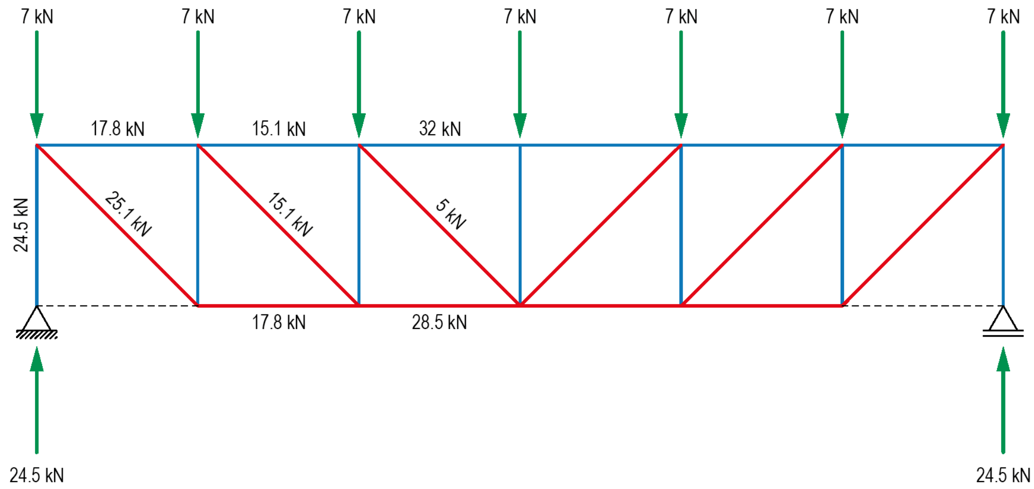
Force diagram

Scale 1 cm ≙ 1 kN



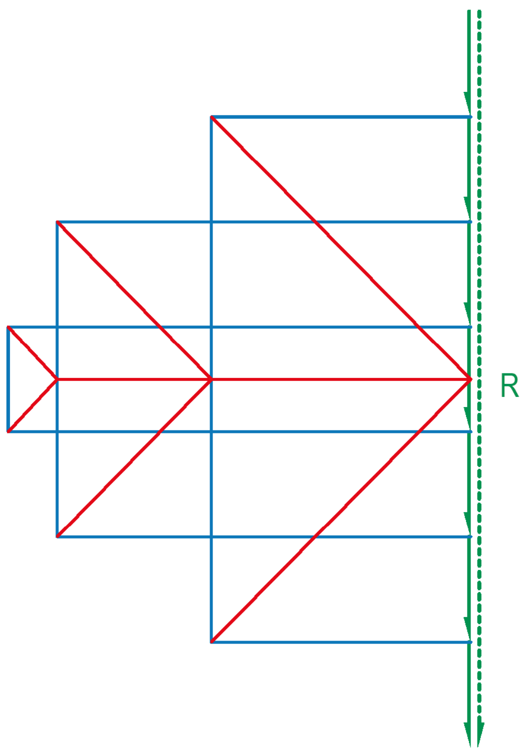
Form diagram

Scale 1 : 100



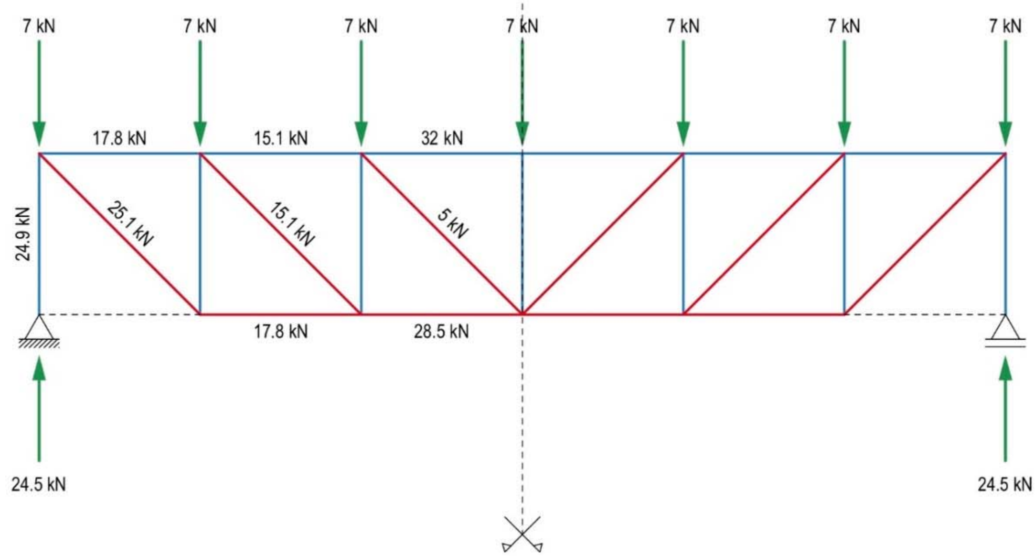
Force diagram

Scale 1 cm ≙ 1 kN



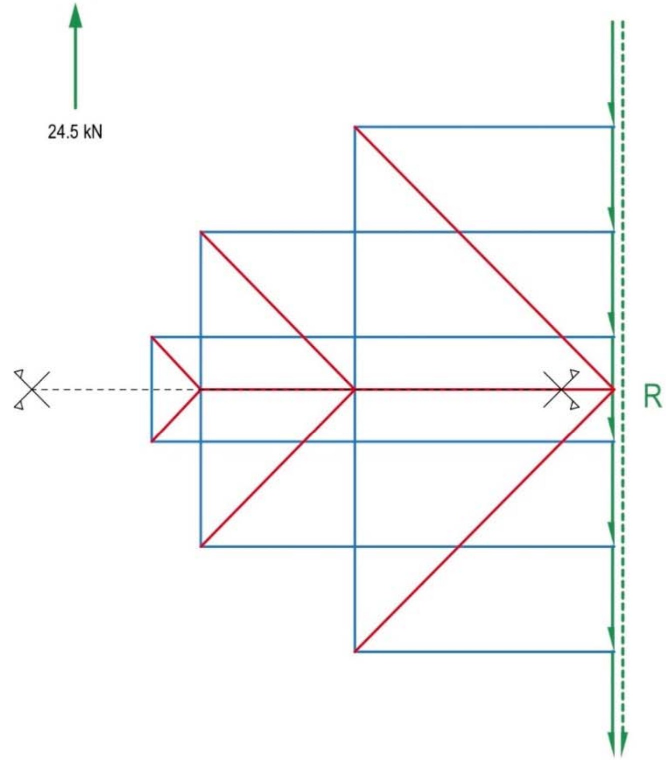
Form diagram

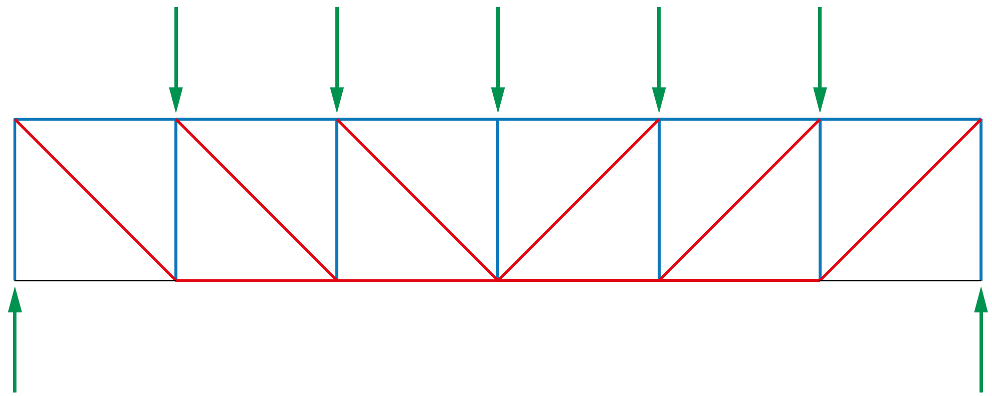
Scale 1 : 100

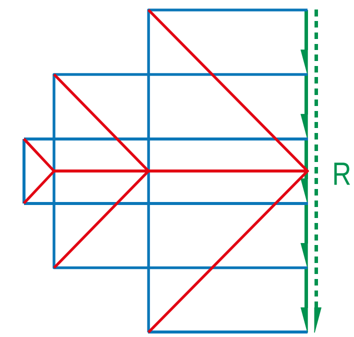


Force diagram

Scale 1 cm ≙ 1 kN



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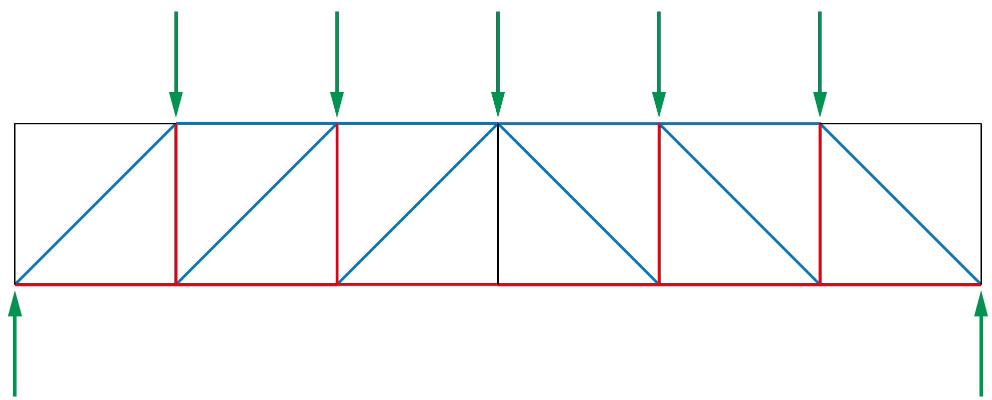

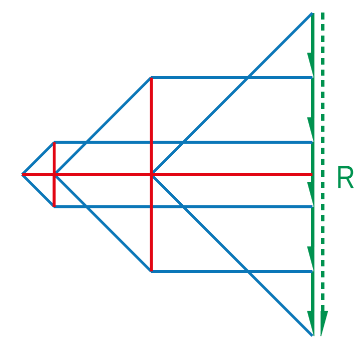
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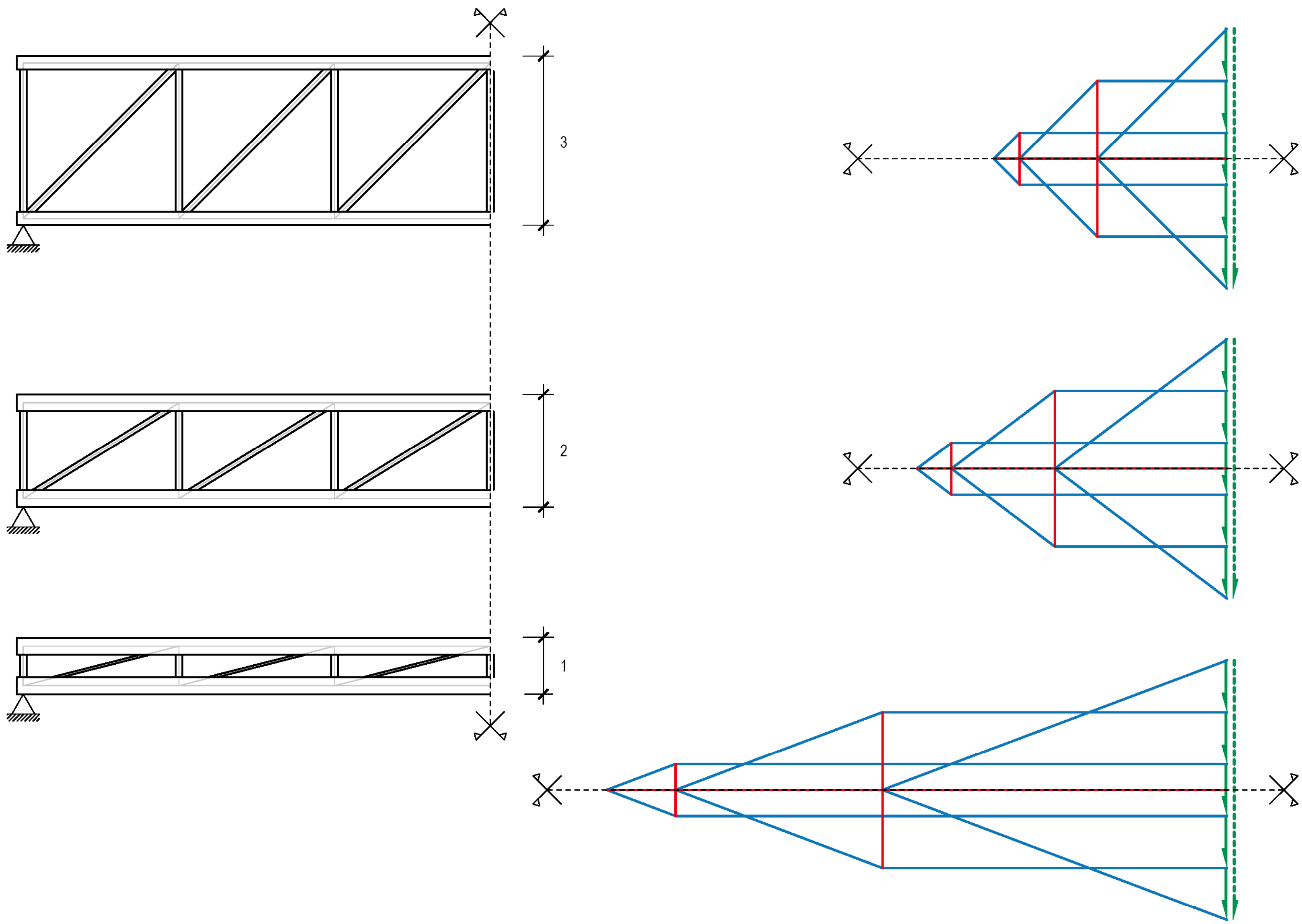
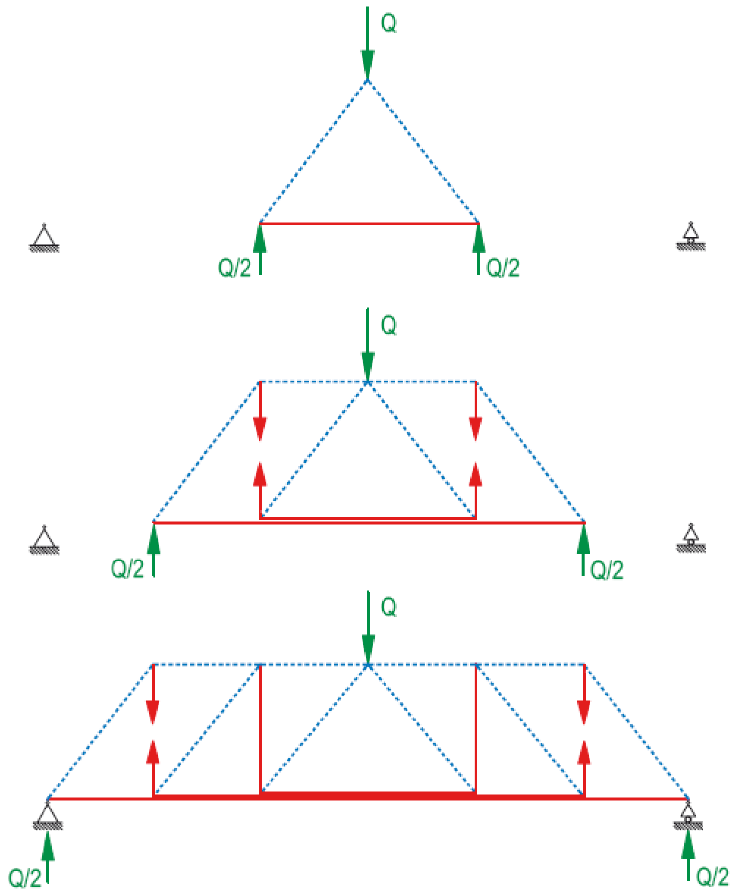
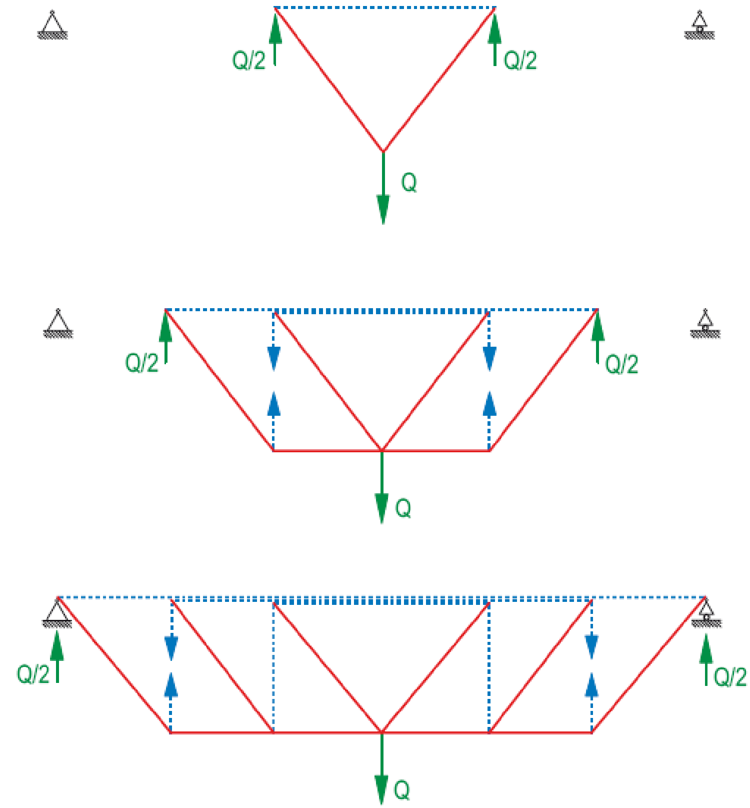

3
2
1


Q
Q/2
Q/2
Q
Q/2
Q/2
Q
Q/2
Q/2


Q/2
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Q
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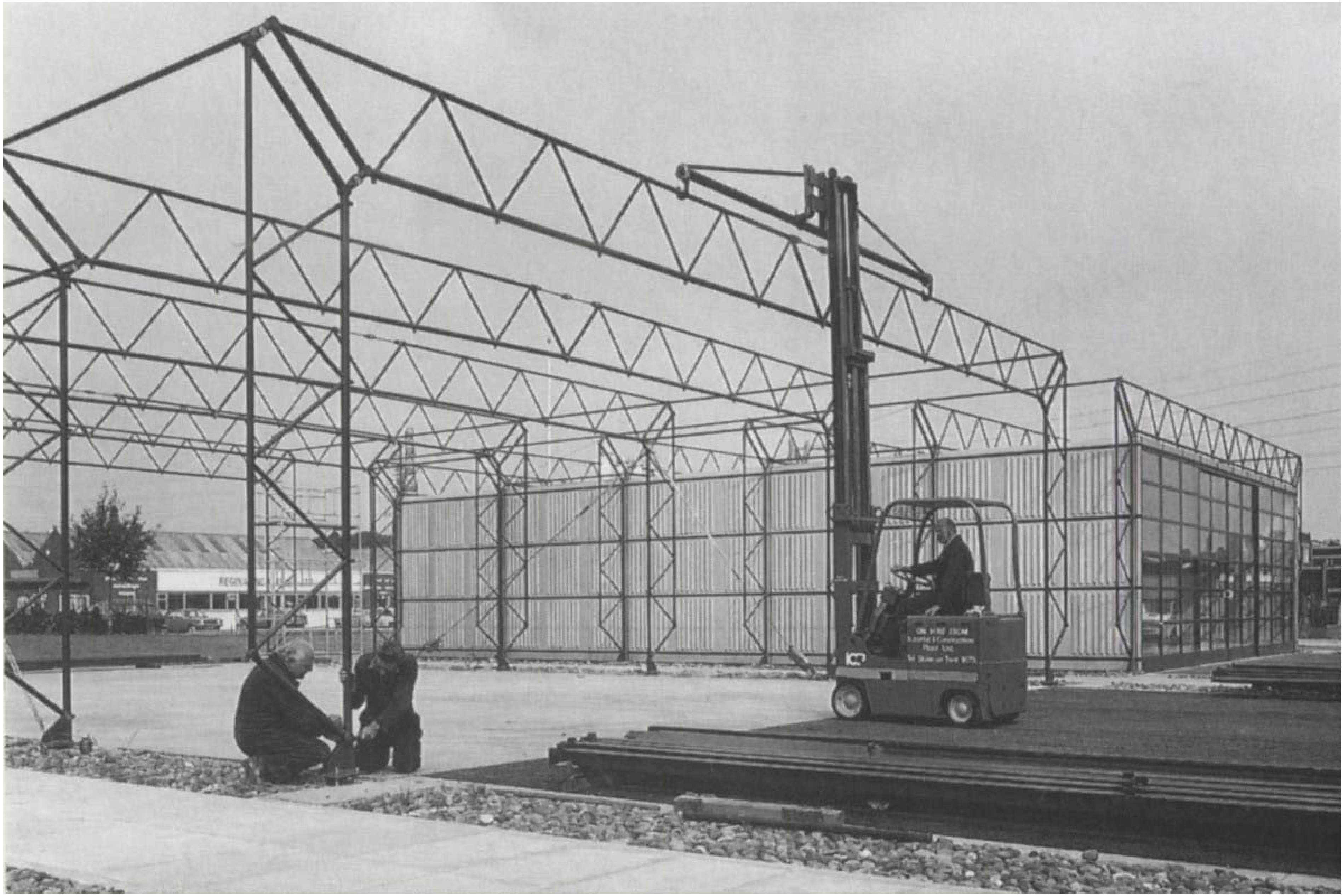
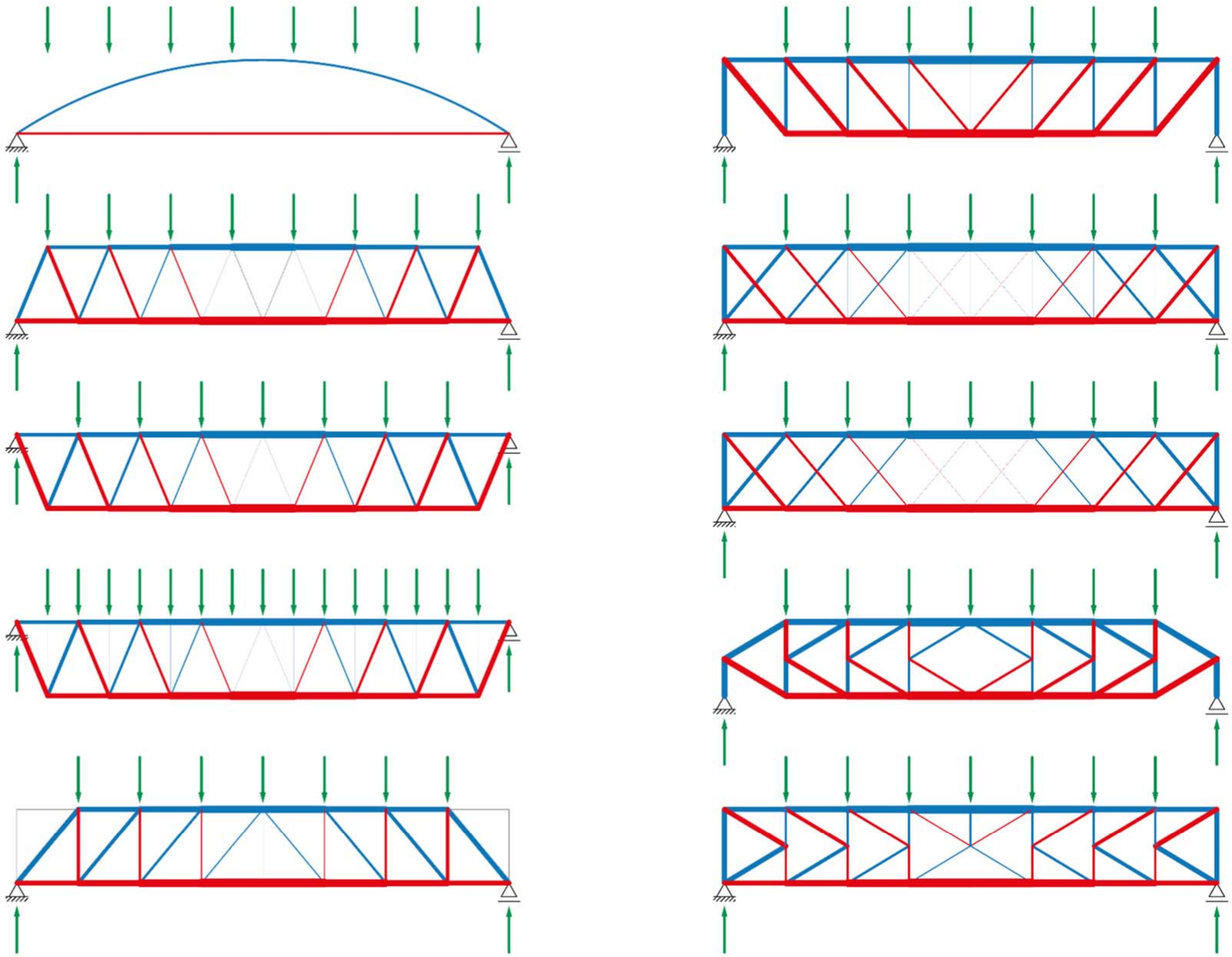
Q



Michael Hopkins, Anthony Hunt, Mark Whitby: Patera Building, Stoke on Trent, 1982

R. Piano, R. Rogers, P. Rice: Centre Georges Pompidou, Paris, 1977



Structural Typologies

Cable structures

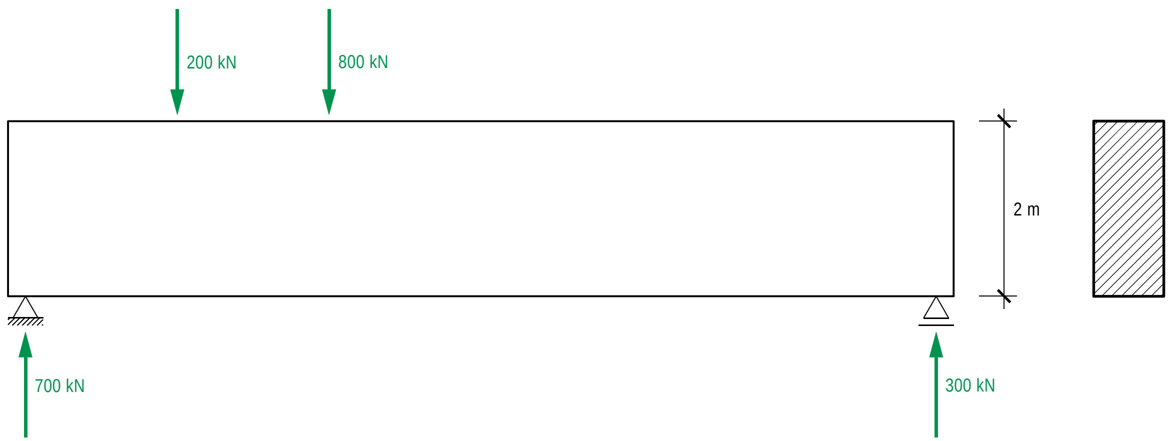
Arches and shells

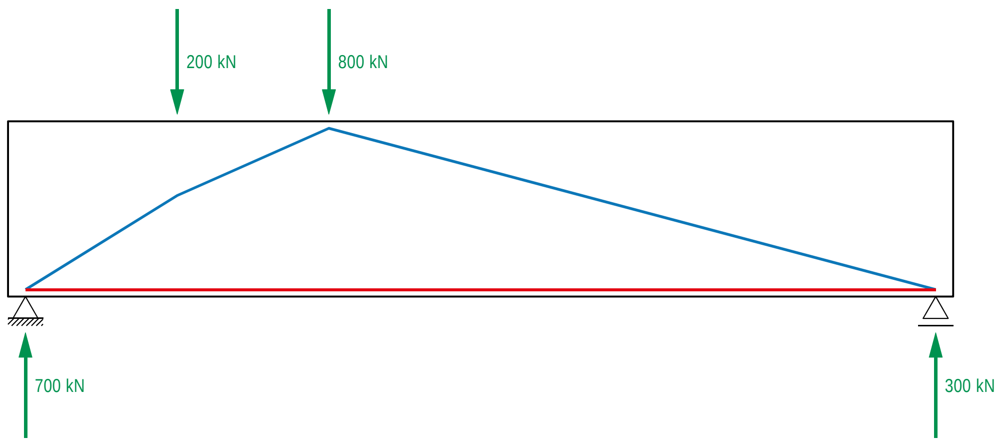
Arch-cable systems

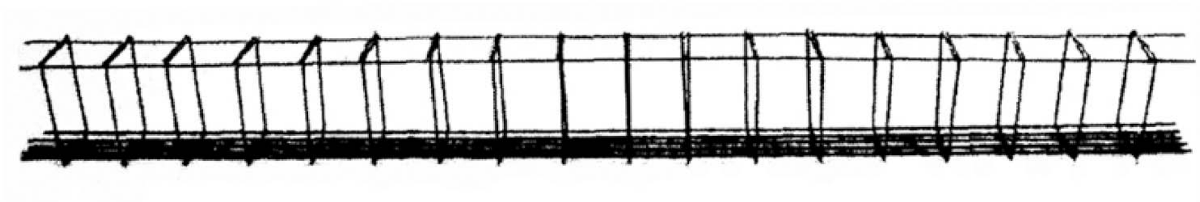
Trusses

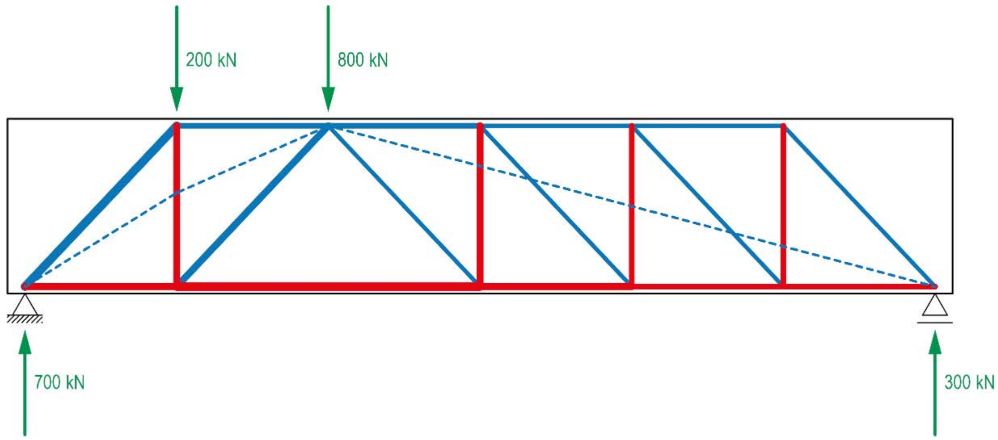
Beams

Frames


200 kN
800 kN
2 m
700 kN
300 kN


200 kN
800 kN
700 kN
300 kN




200 kN
800 kN
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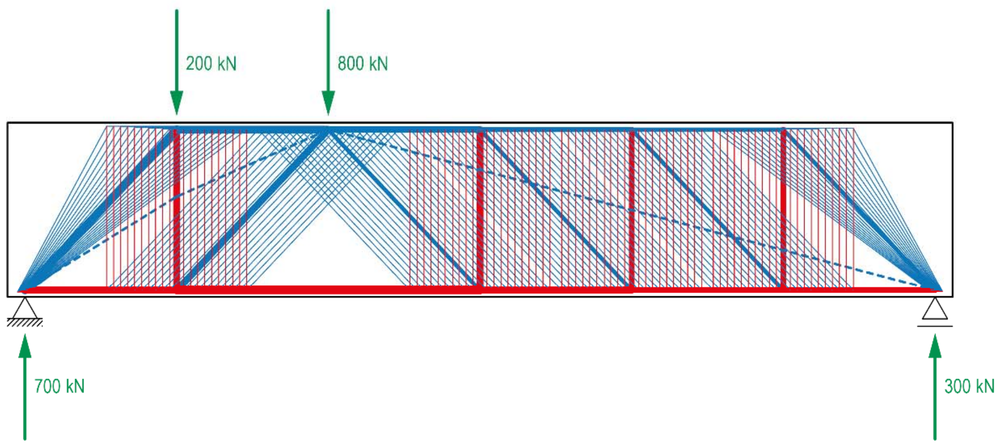
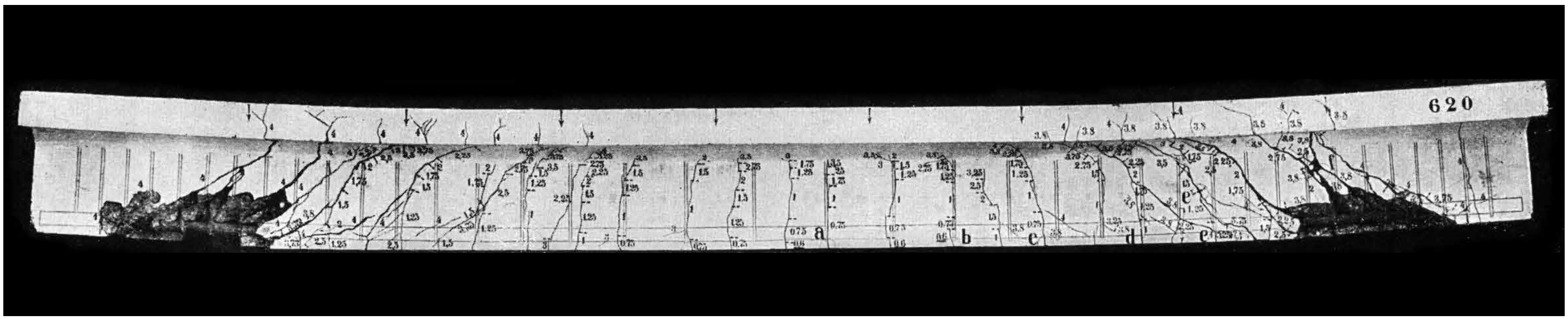
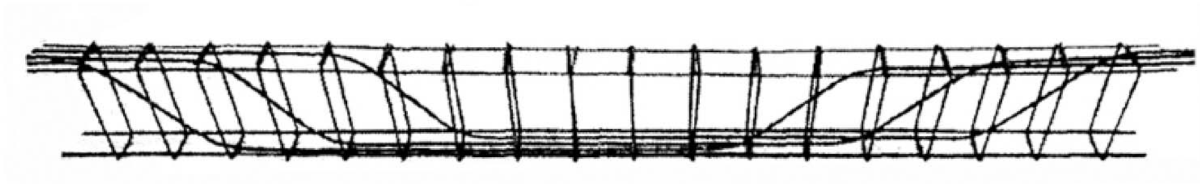
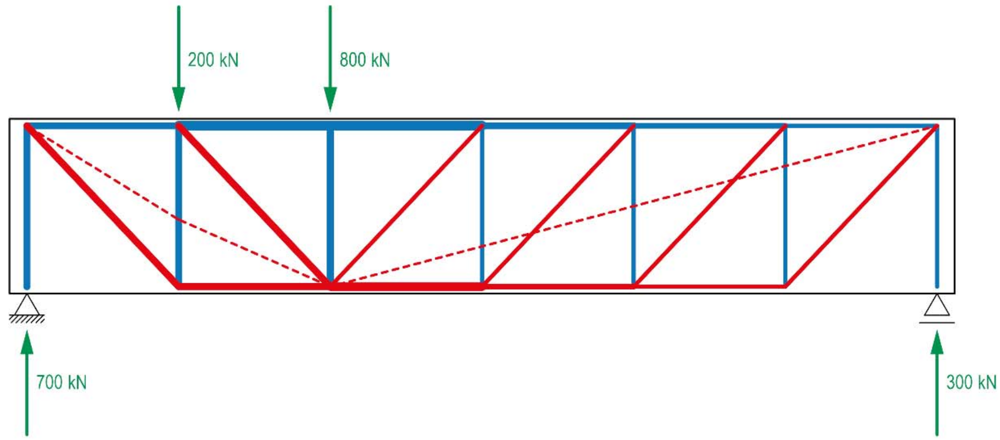
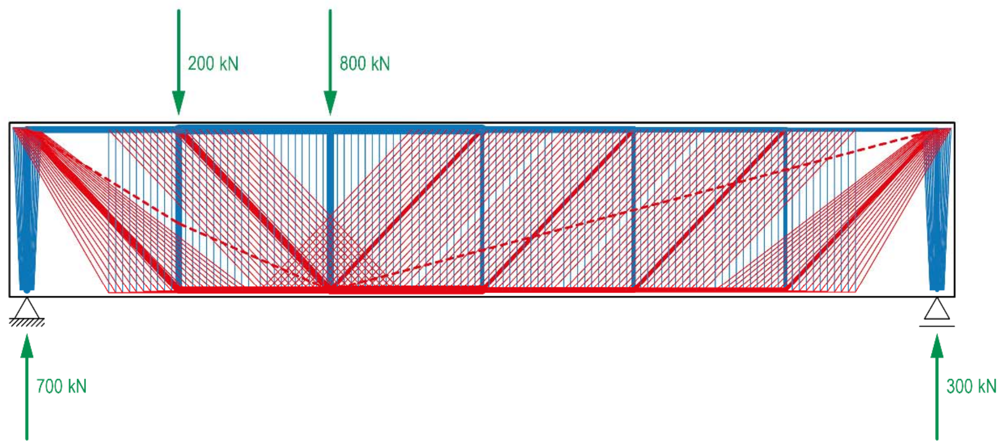
300 kN


200 kN
800 kN
700 kN
300 kN

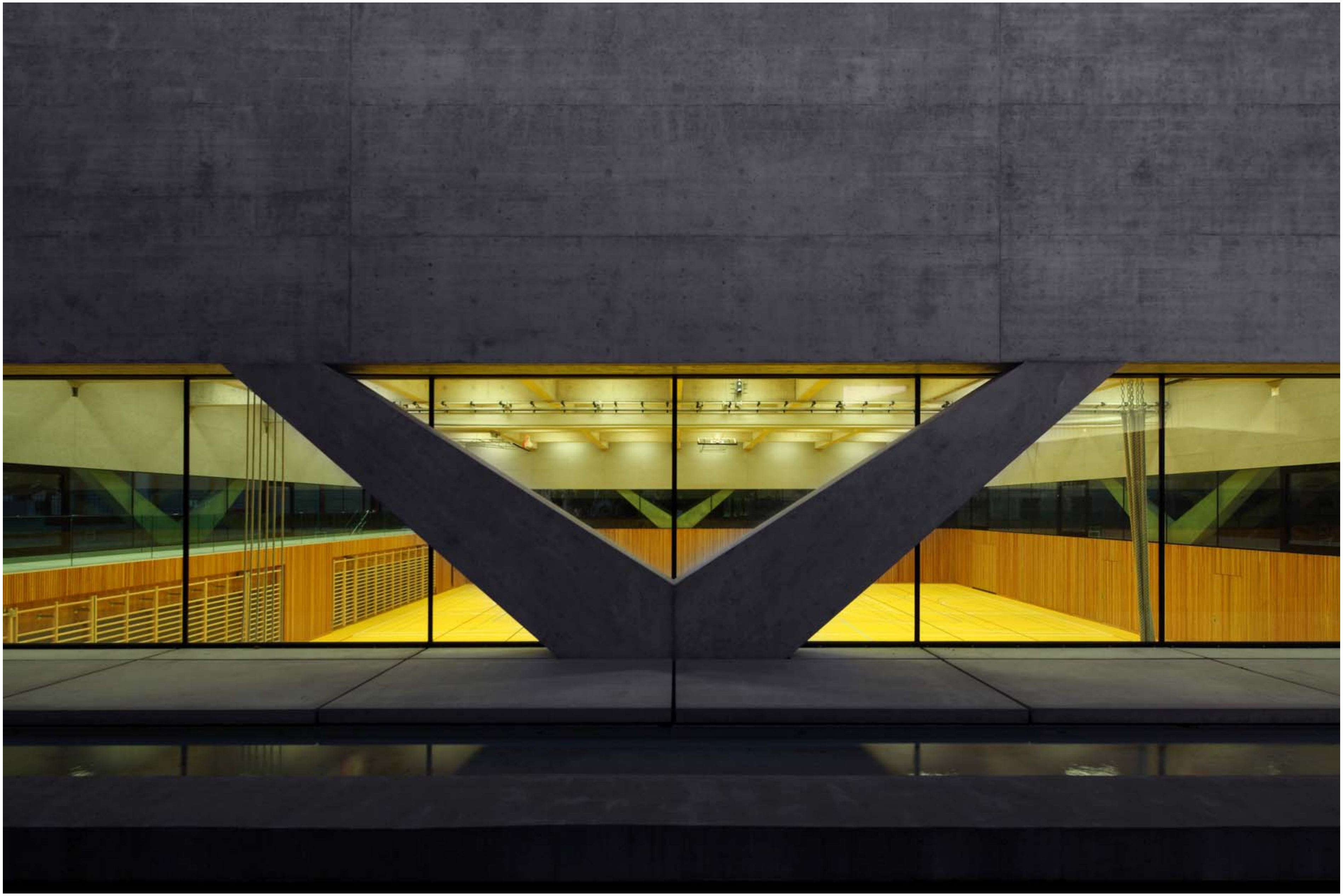

620



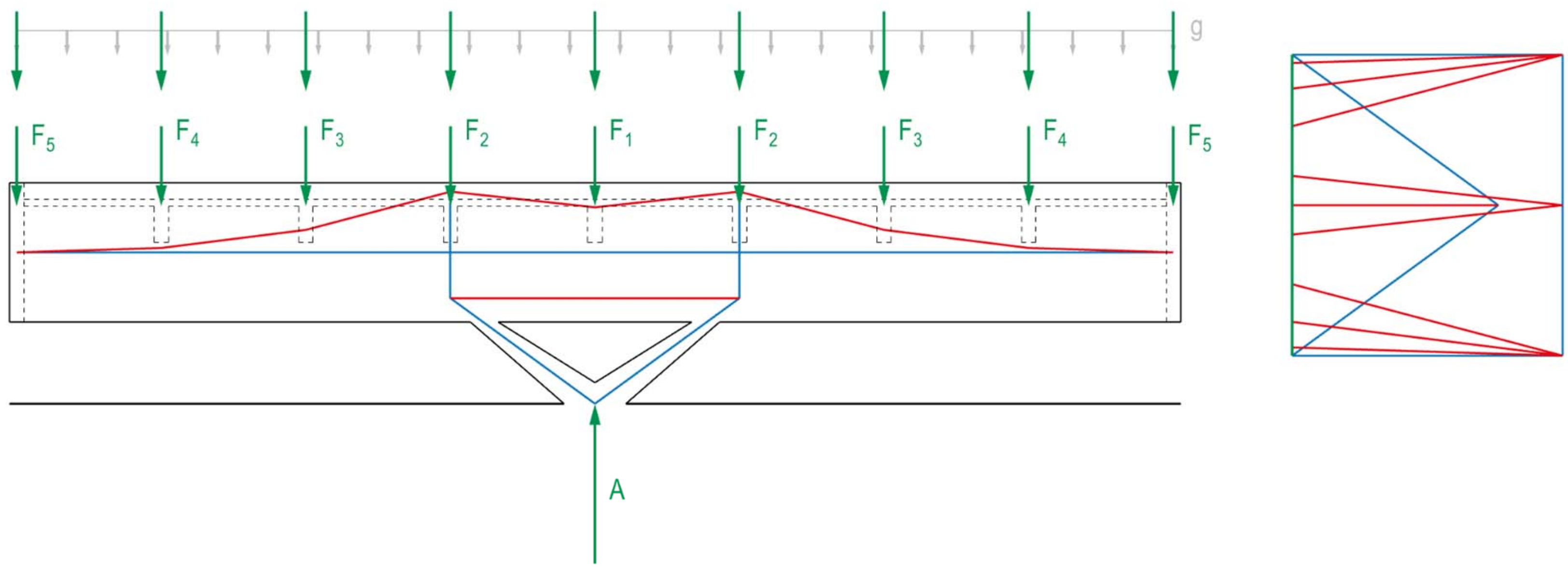

200 kN
800 kN
700 kN
300 kN


200 kN
800 kN
700 kN
300 kN

Baserga, Mozzetti, Pedrazzini, Guidotti: Palestra Doppia, Chiasso, 2010



baserga mozzetti and Pedrazzini: Palestra Doppia, Chiasso, 2010



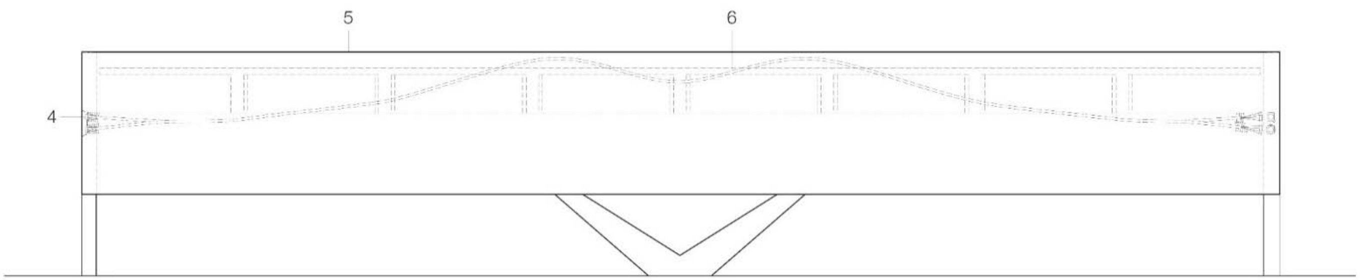
baserga mozzetti and Pedrazzini: Palestra Doppia, Chiasso, 2010

Position Vorspannseile
Dachträger/Außenwand
Maßstab 1:200

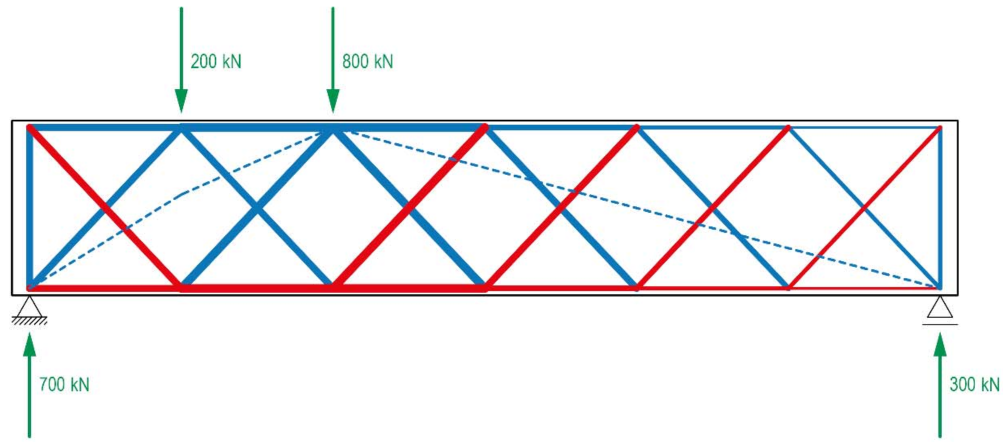
1 Dachträger
2 Spannseil Stahl in Hüllrohr Ø 116 mm
3 Spannseil Stahl in Hüllrohr Ø 91 mm
4 seitliche Spannseil-verankerung
5 Stahlbeton-Wand-scheibe
6 Spannseil Stahl in Hüllrohr Ø 73 mm

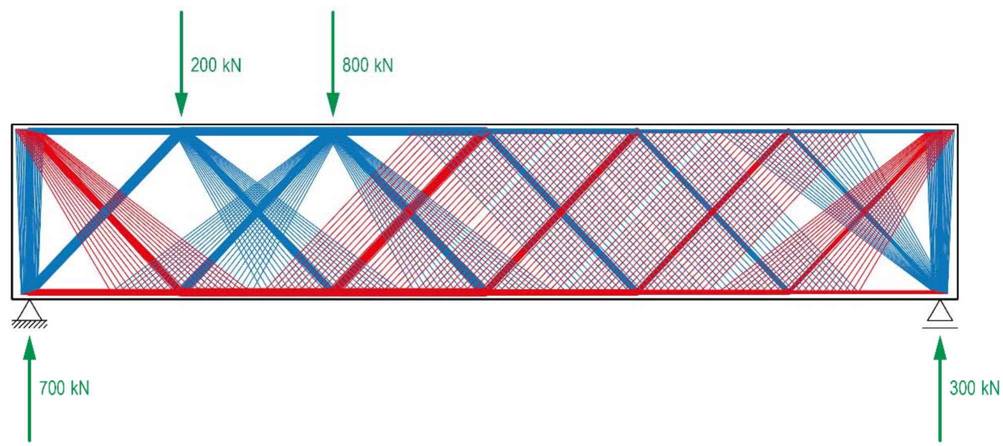
Pre-tension cables
Roof beams/Exterior wall
Scale 1:200

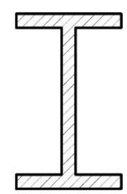
1 roof beam
2 steel tension cable in Ø 116 mm tube
3 steel tension cable in Ø 91 mm tube
4 lateral tension-cable anchor
5 lateral reinforced-concrete slab
6 steel tension cable in Ø 73 mm tube



baserga mozzetti and Pedrazzini: Palestra Doppia, Chiasso, 2010

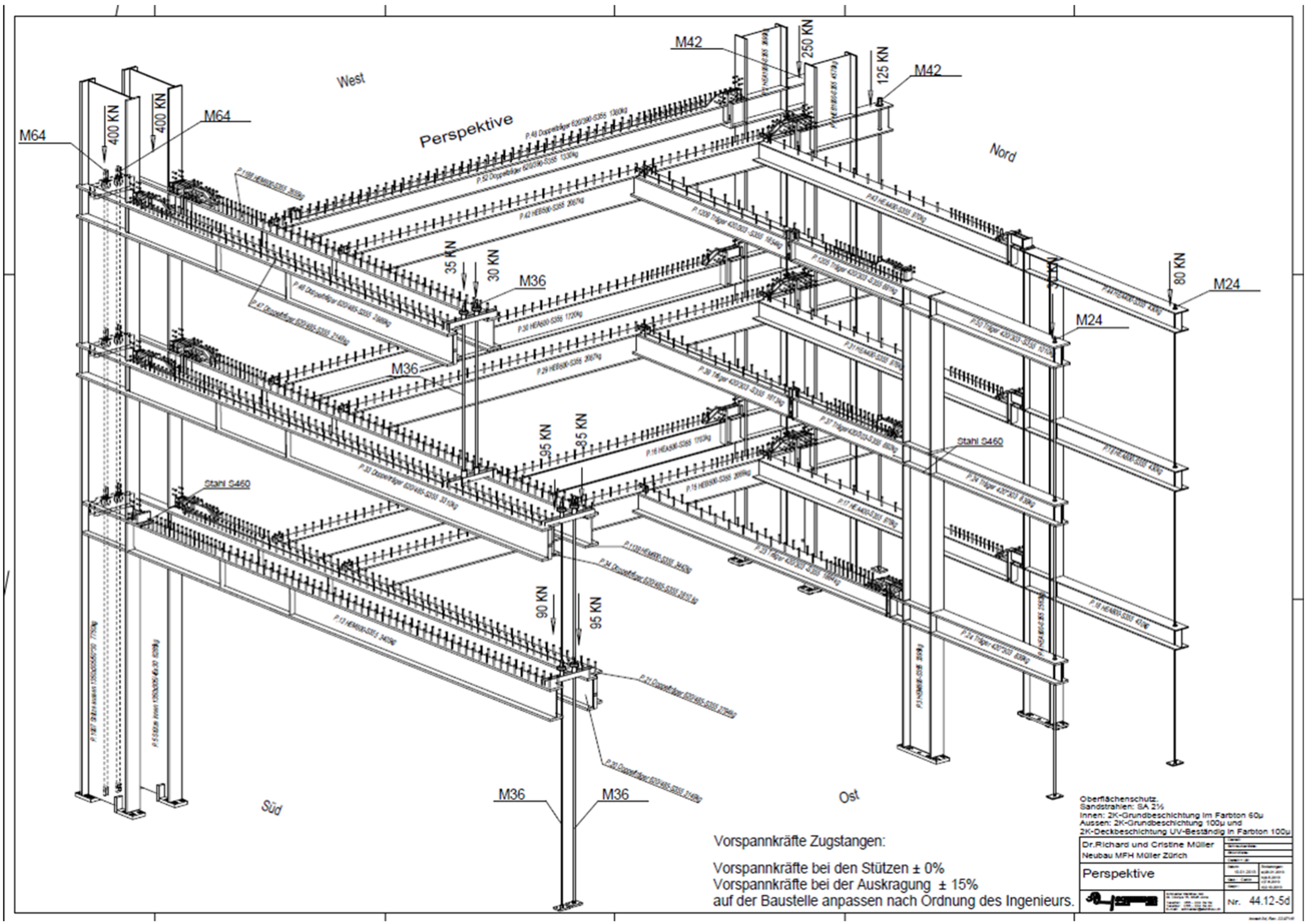






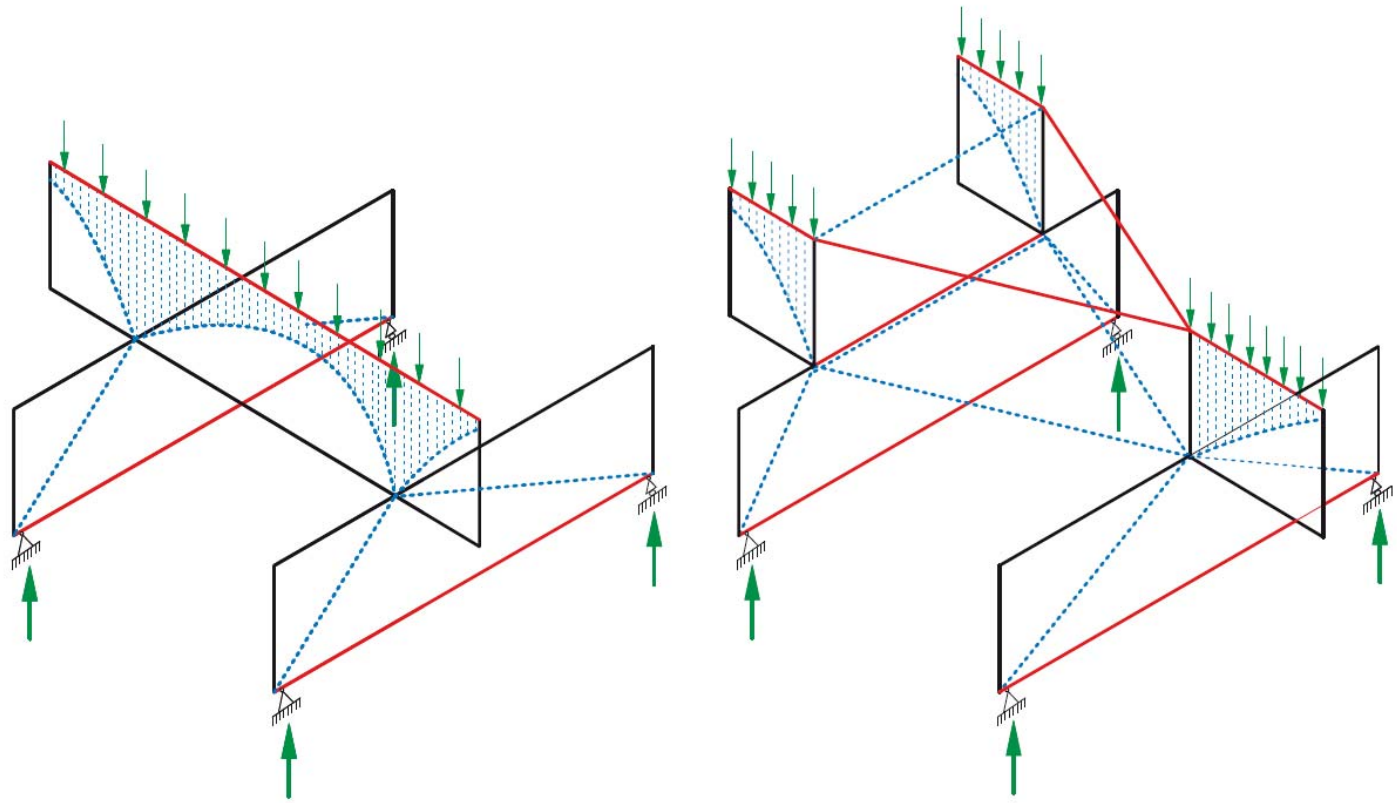
Steel

Haus Müller, Zurich, Arch.: Christian Kerez, Eng.: Joseph Schwartz, 2013



Haus Müller, Zurich, Arch.: Christian Kerez, Eng.: Joseph Schwartz, 2013

Haus Müller, Zurich, Arch.: Christian Kerez, Eng.: Joseph Schwartz, 2013



Haus Forsterstrasse, Zurich, Arch.: Christian Kerez, Eng.: Joseph Schwartz, 2003

Haus Forsterstrasse, Zurich, Arch.: Christian Kerez, Eng.: Joseph Schwartz, 2003

Structural Typologies

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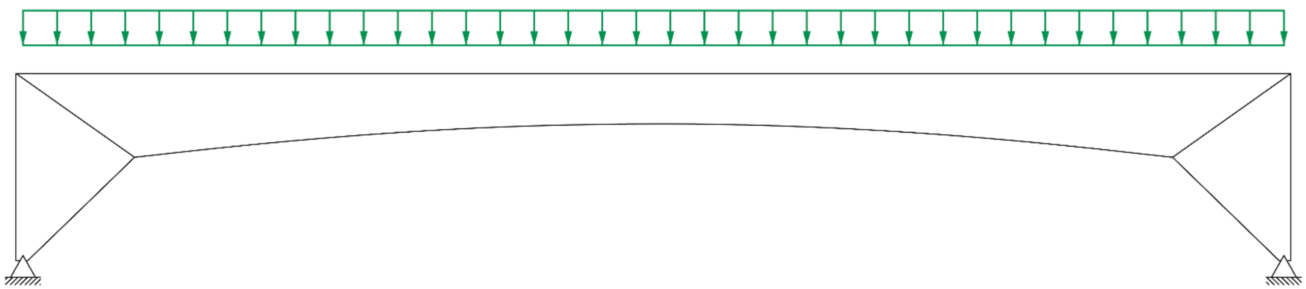
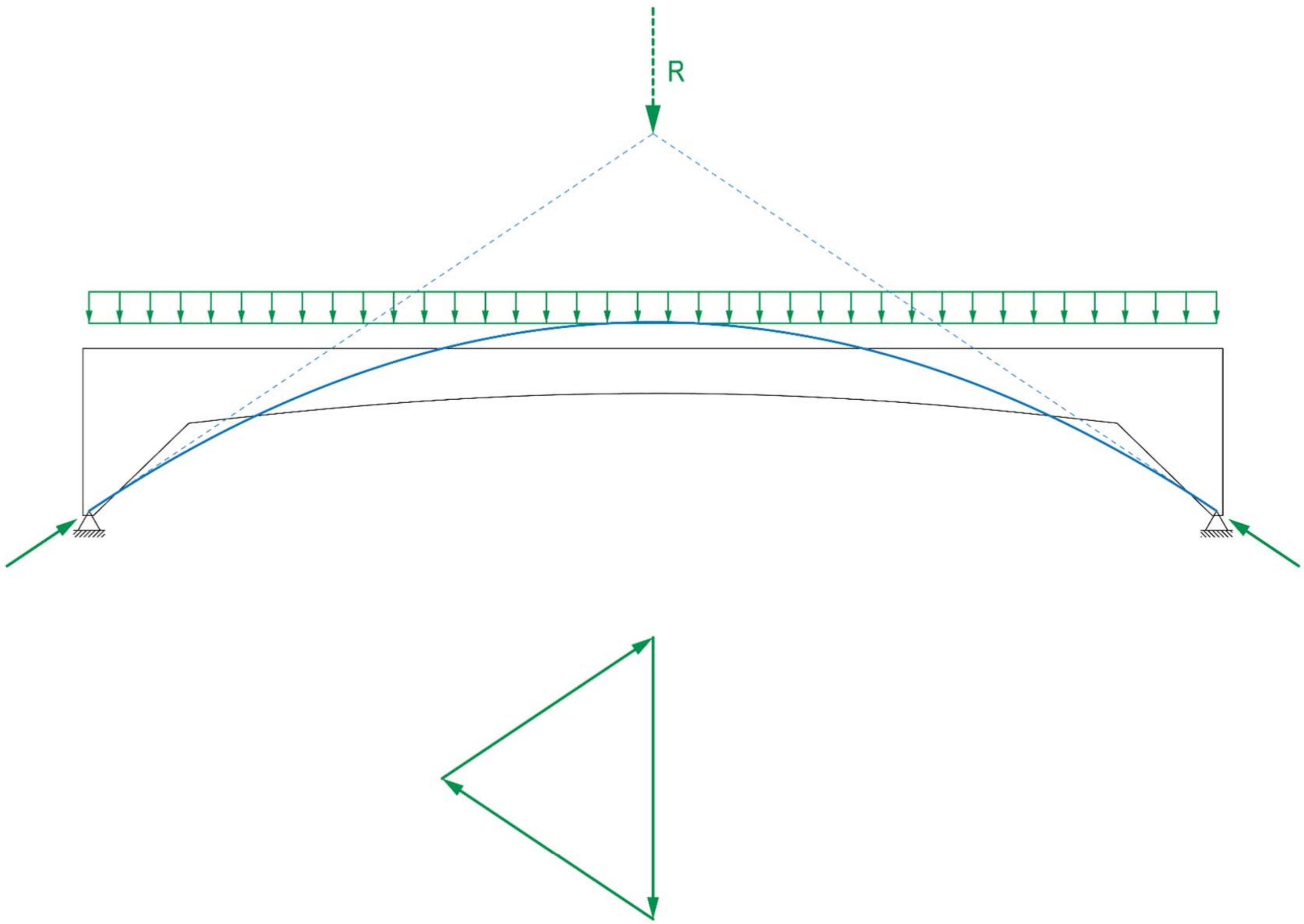
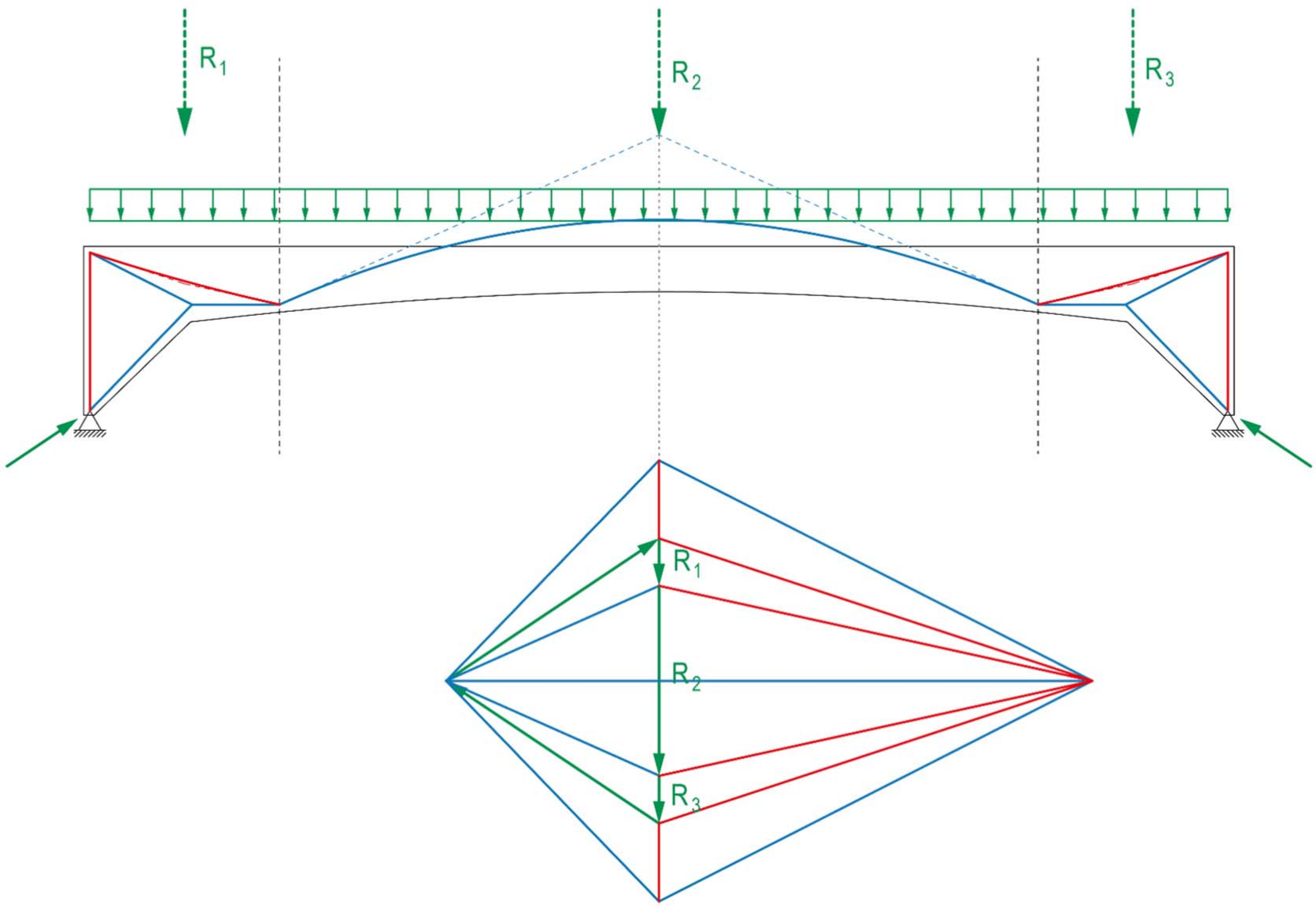
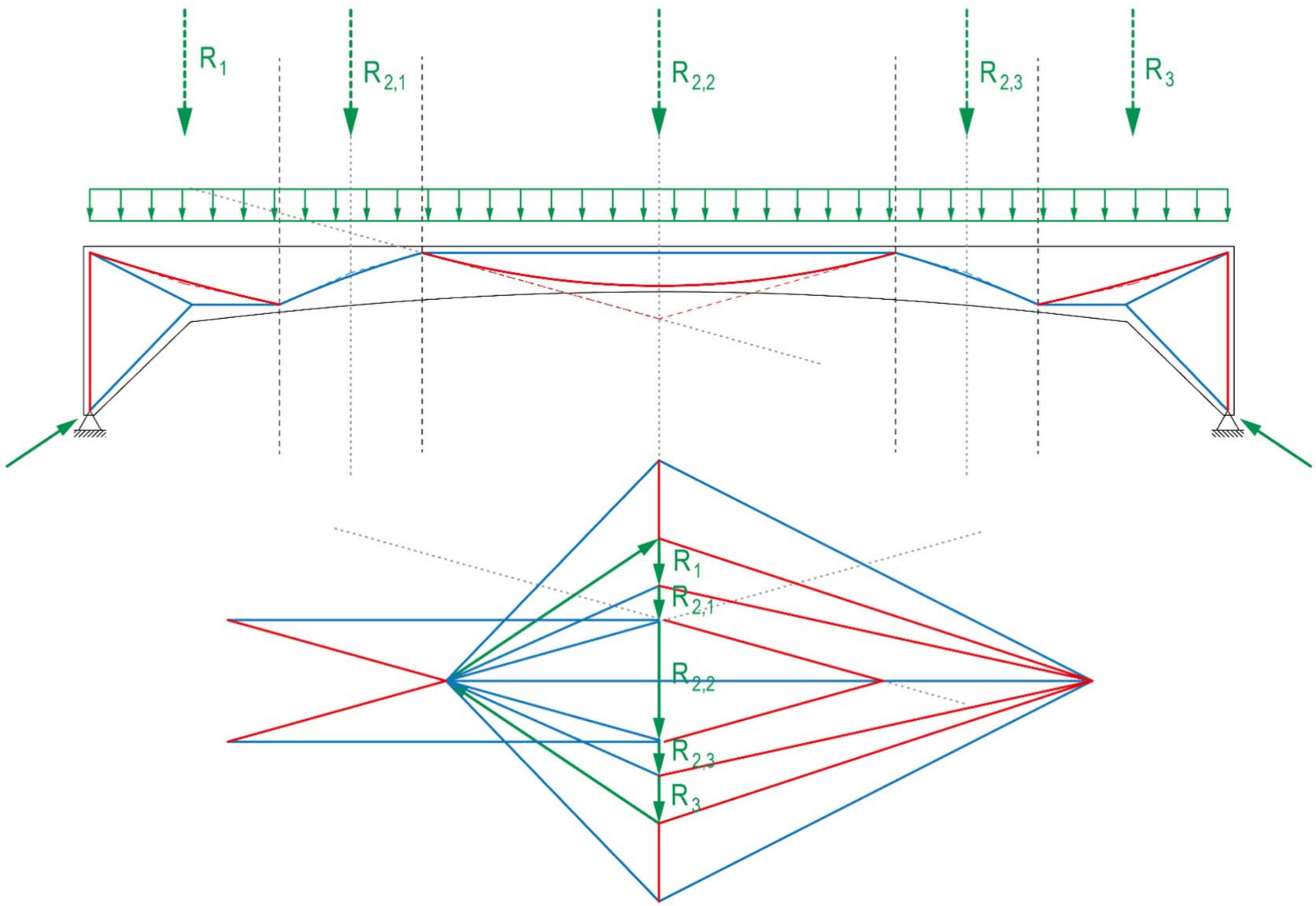
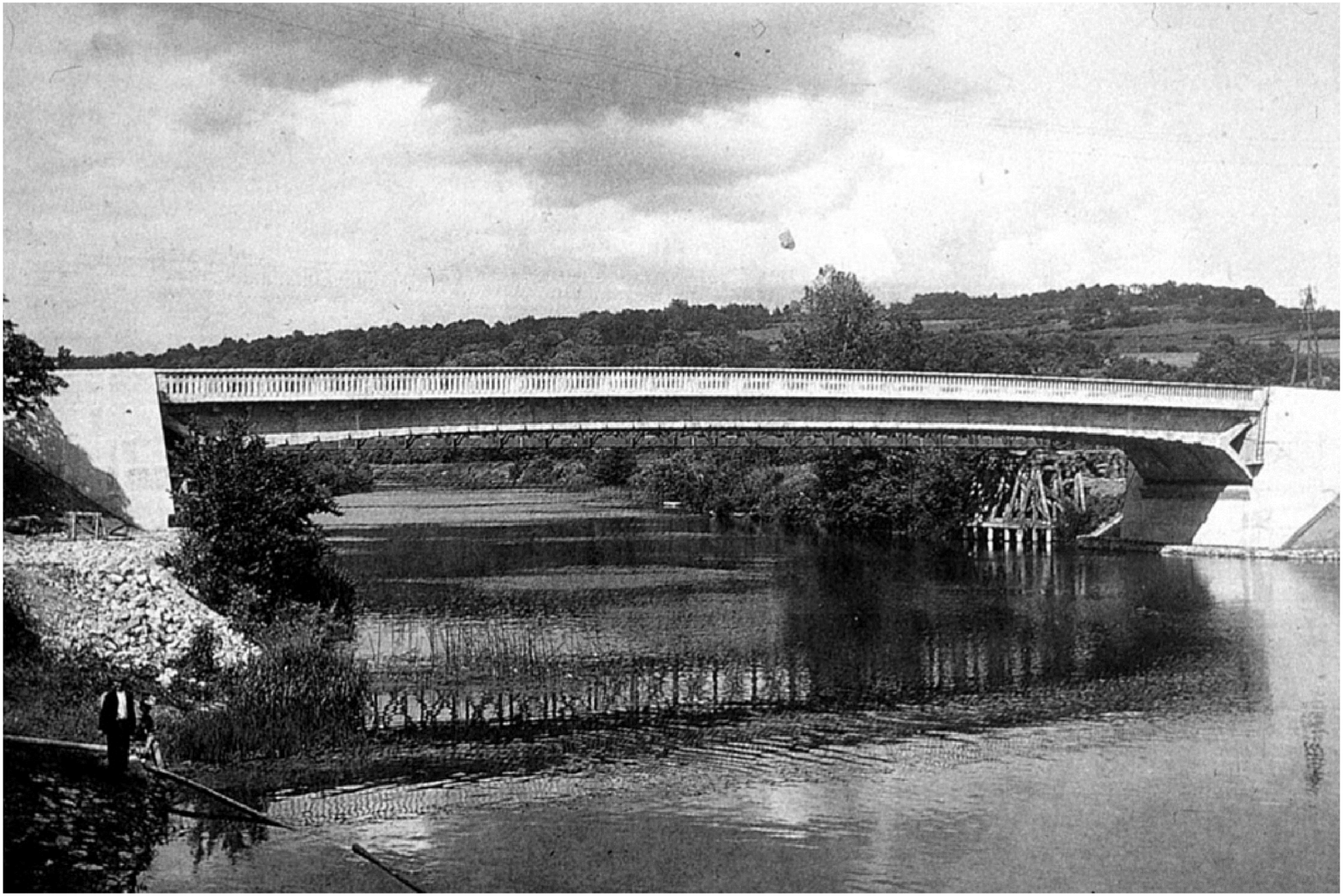


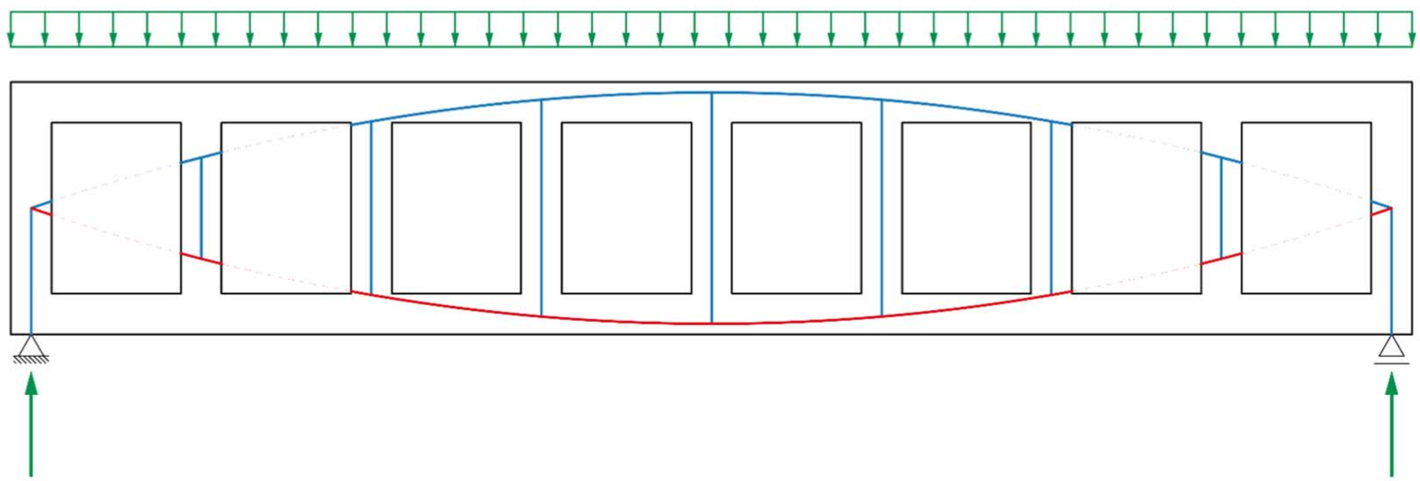

R

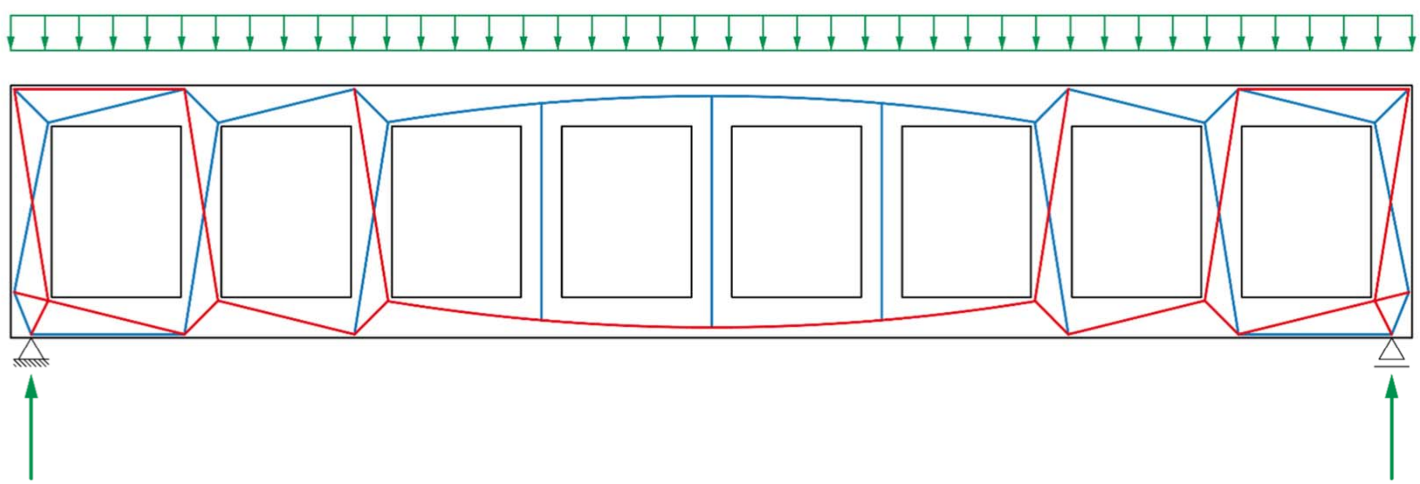

R1
R2
R3
R1
R2
R3


R1
R2,1
R2,2
R2,3
R3
R1
R2,1
R2,2
R2,3
R3

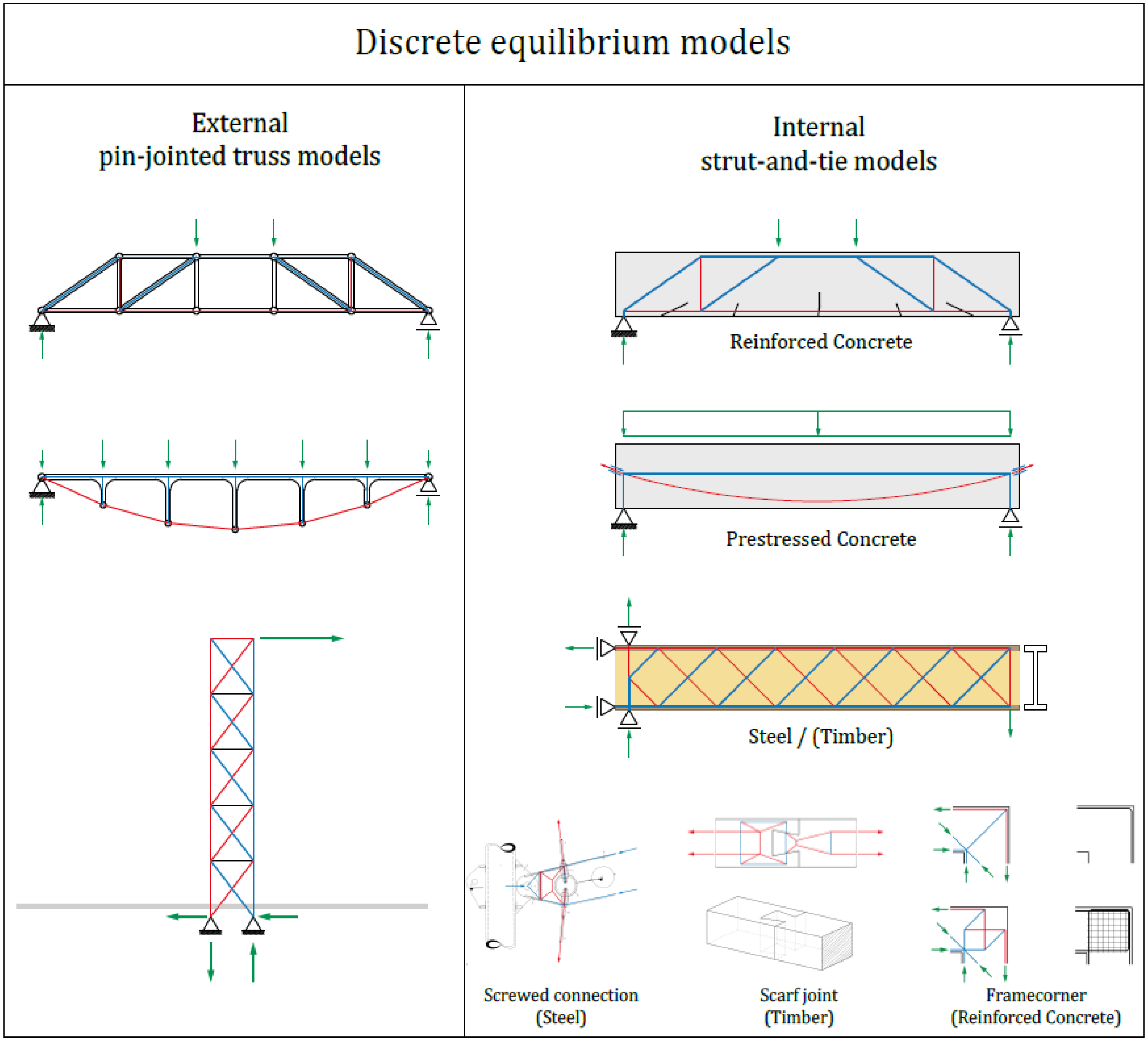


Eugene Freyssinet: Brücke über die Marne, Luzanzy, 1946

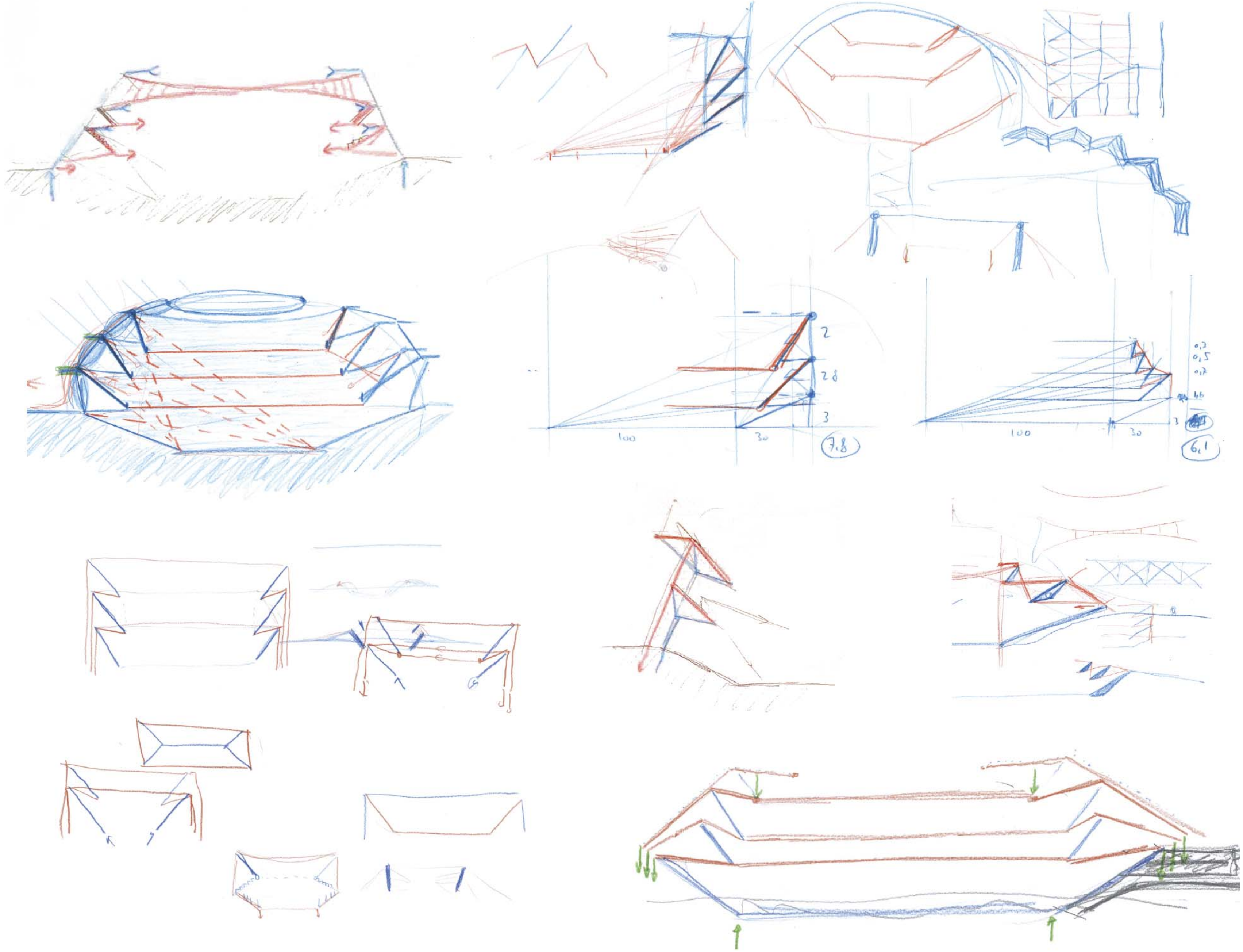




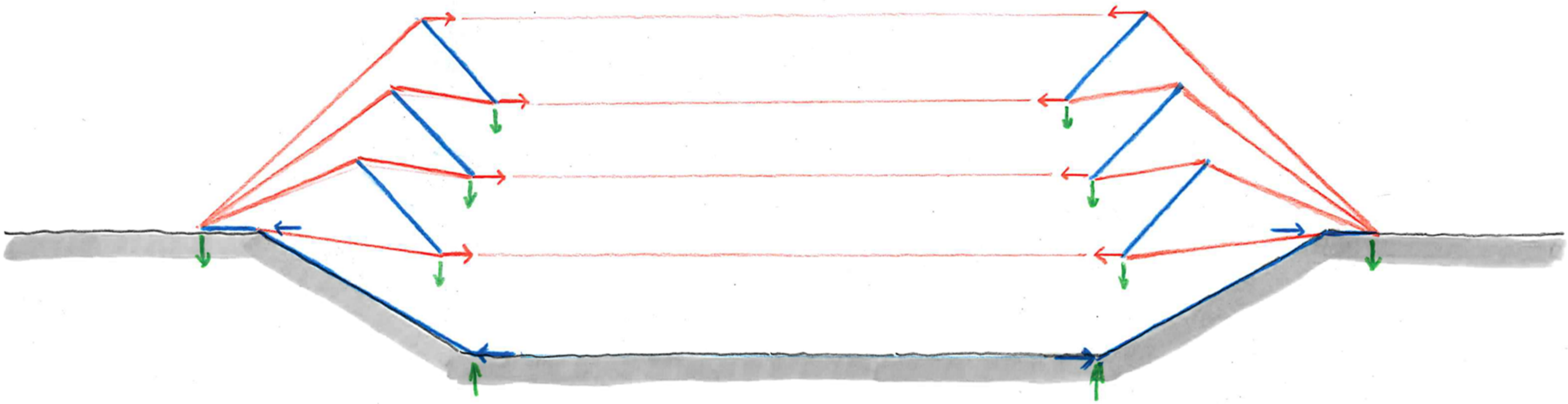
Livio Vacchini, Andreoutti + Partners: Bürohaus La Ferriera, Locarno, 2003

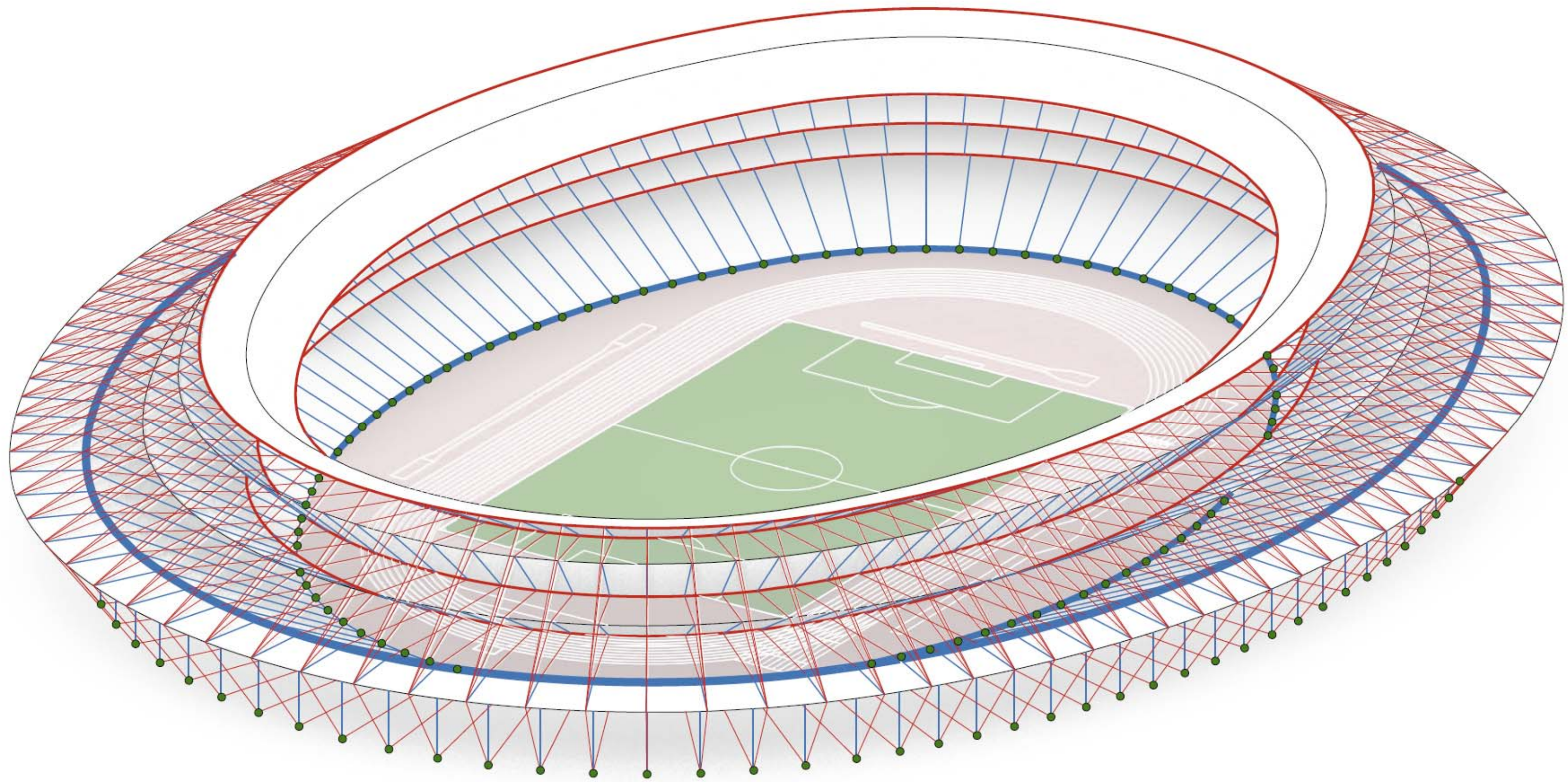

Discrete equilibrium models
External
pin-jointed truss models
Internal
strut-and-tie models
Reinforced Concrete
Prestressed Concrete
Steel / (Timber)
Screwed connection
(Steel)
Scarf joint
(Timber)
Framecorner
(Reinforced Concrete)

Beyond Typologies

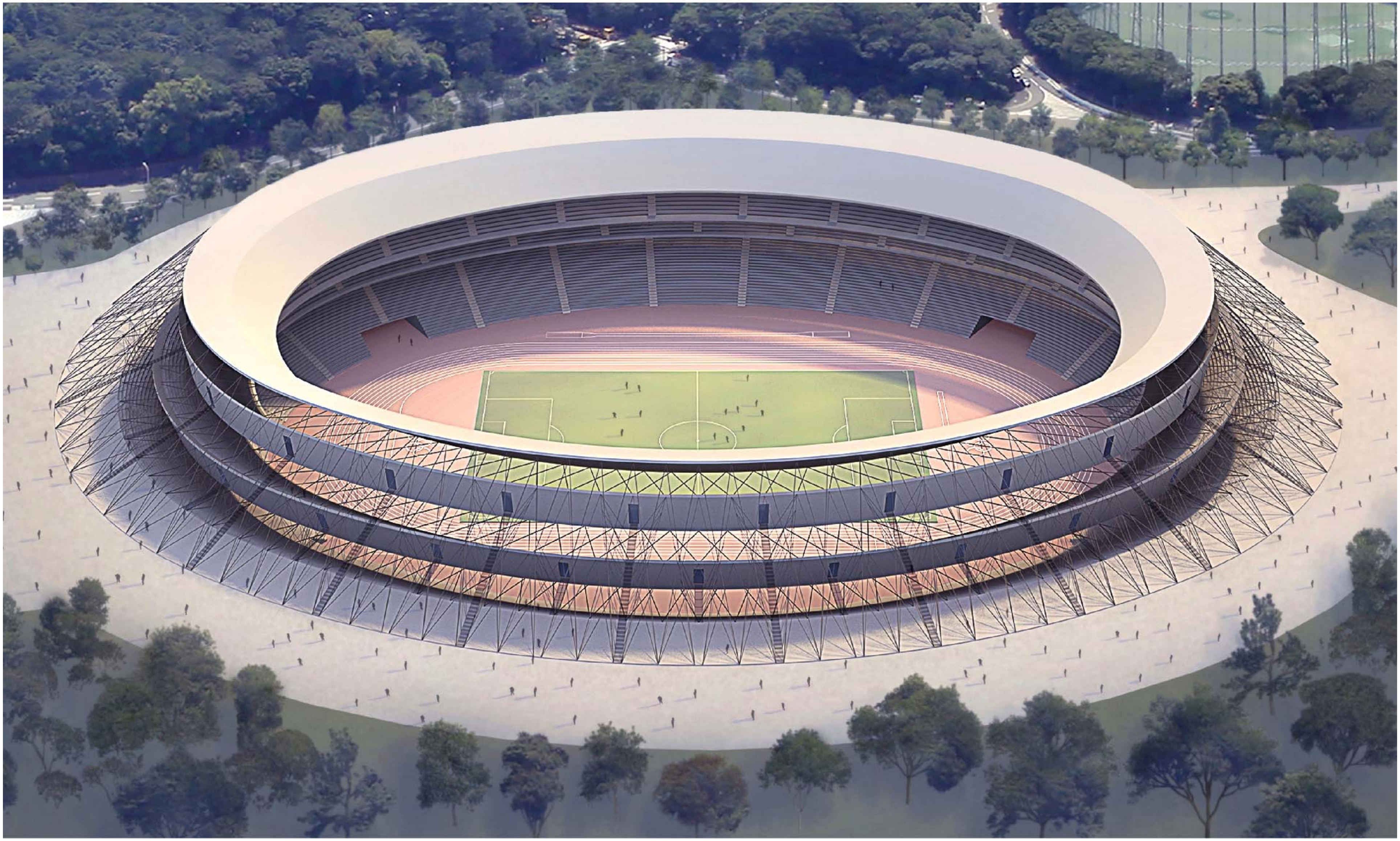


Sketches National Stadium Tokyo 2020 - P. D’Acunto, L. Ingold, O. P. Ohlbrock - 2016

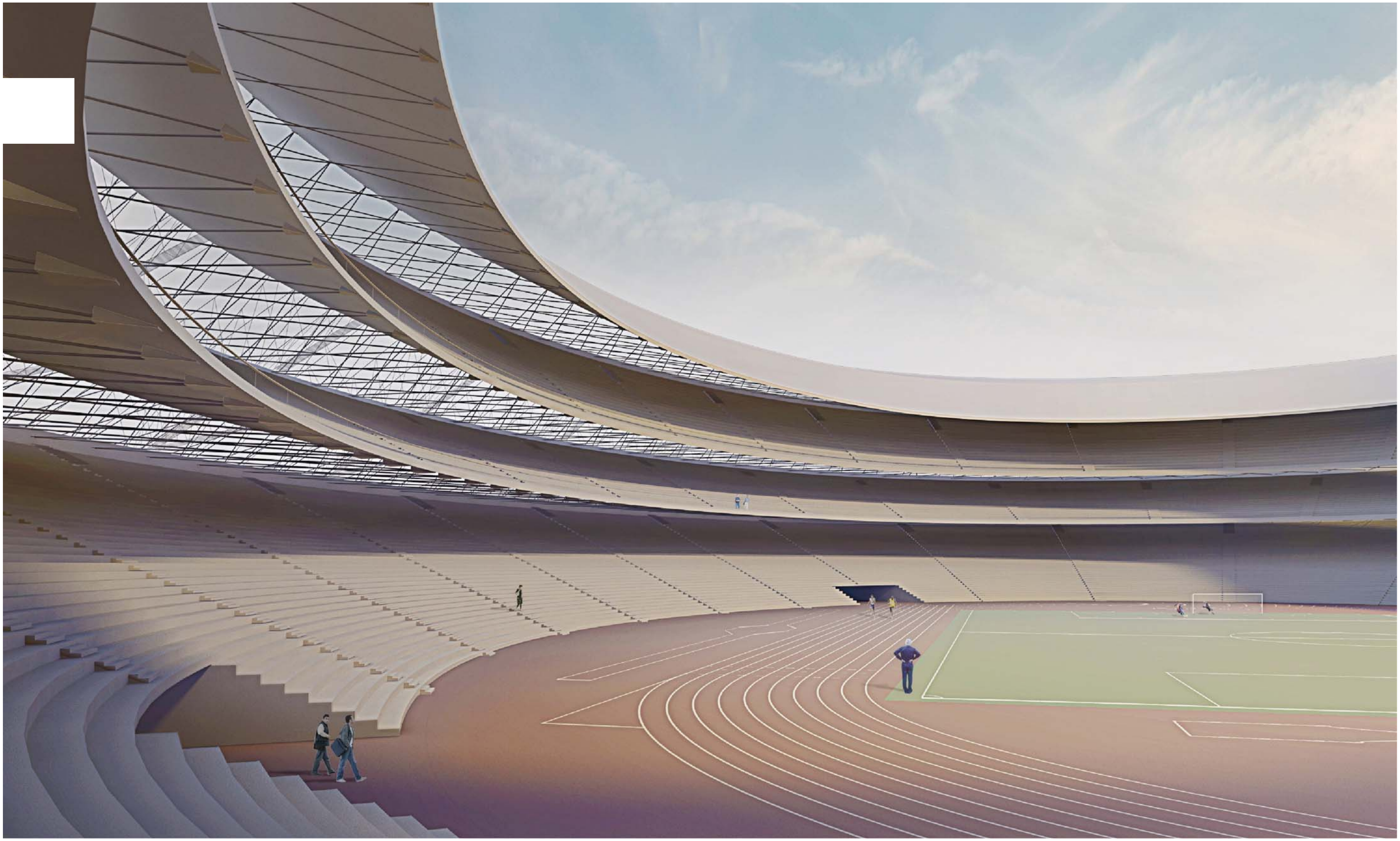




Structural Diagrams National Stadium Tokyo 2020 - P. D’Acunto, L. Ingold, O. P. Ohlbrock - 2016

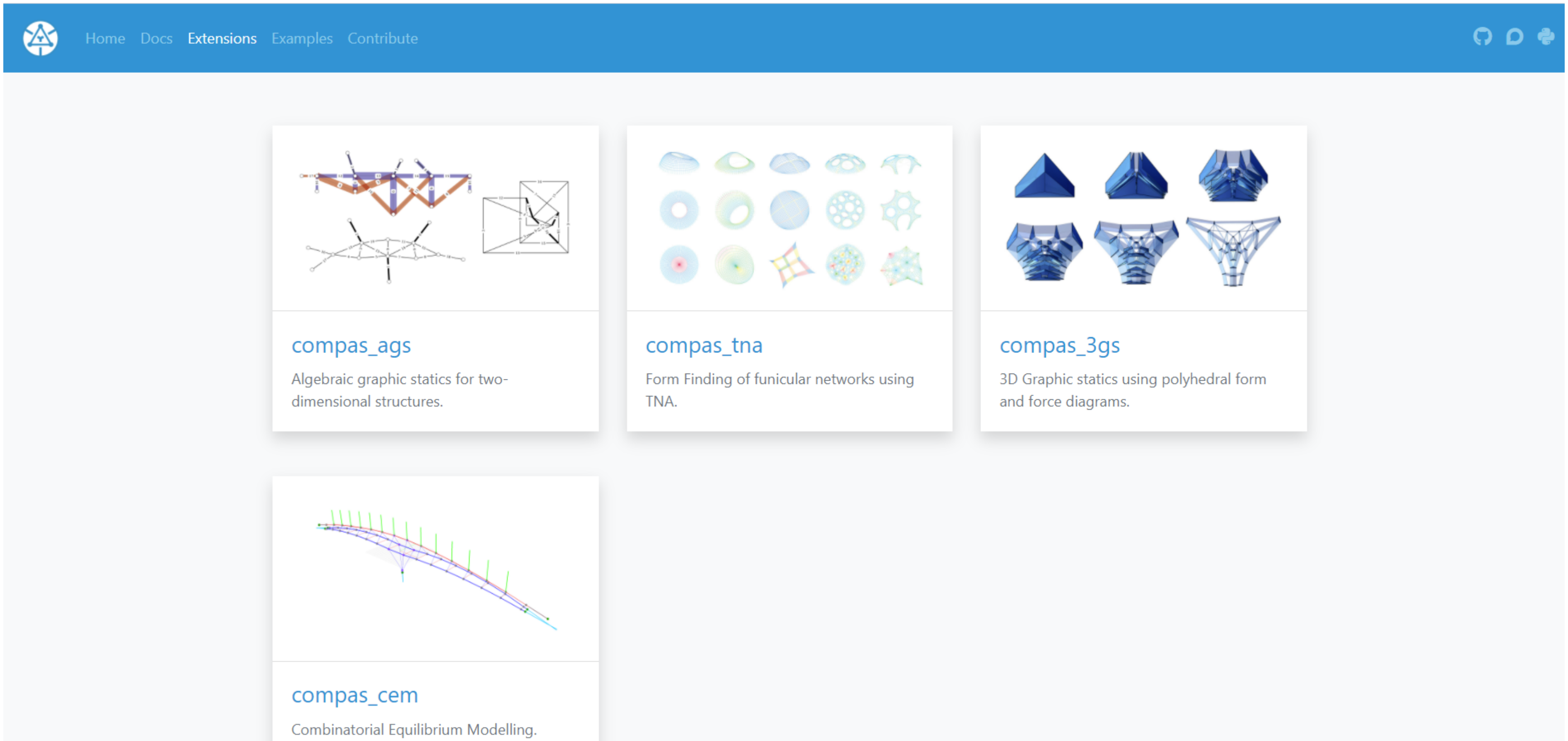


National Stadium Tokyo 2020 - P. D'Acunto, L. Ingold, O. P. Ohlbrock - 2016



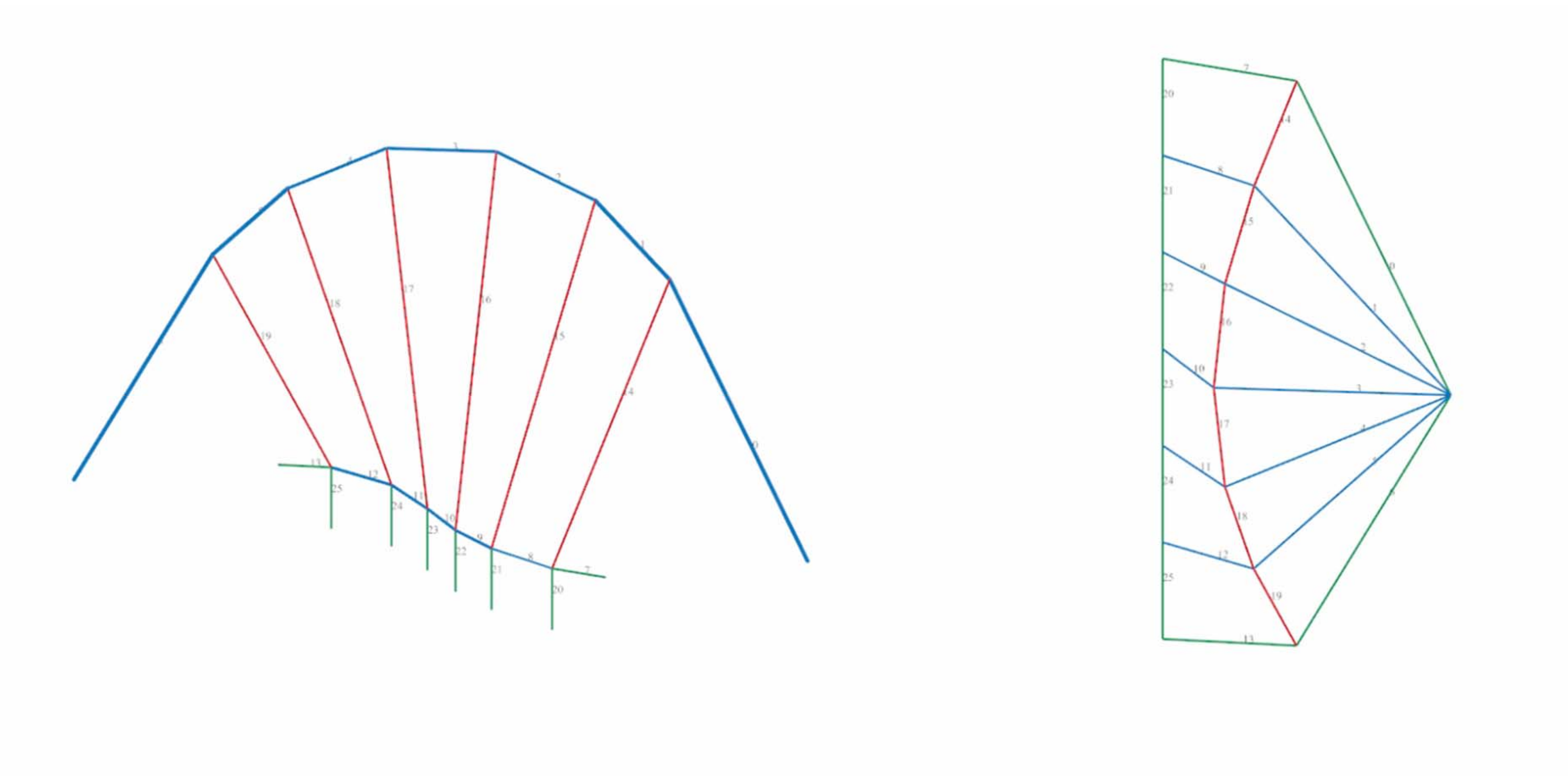
National Stadium Tokyo 2020 - P. D'Acunto, L. Ingold, O. P. Ohlbrock - 2016

Computational Equilibrium Tools

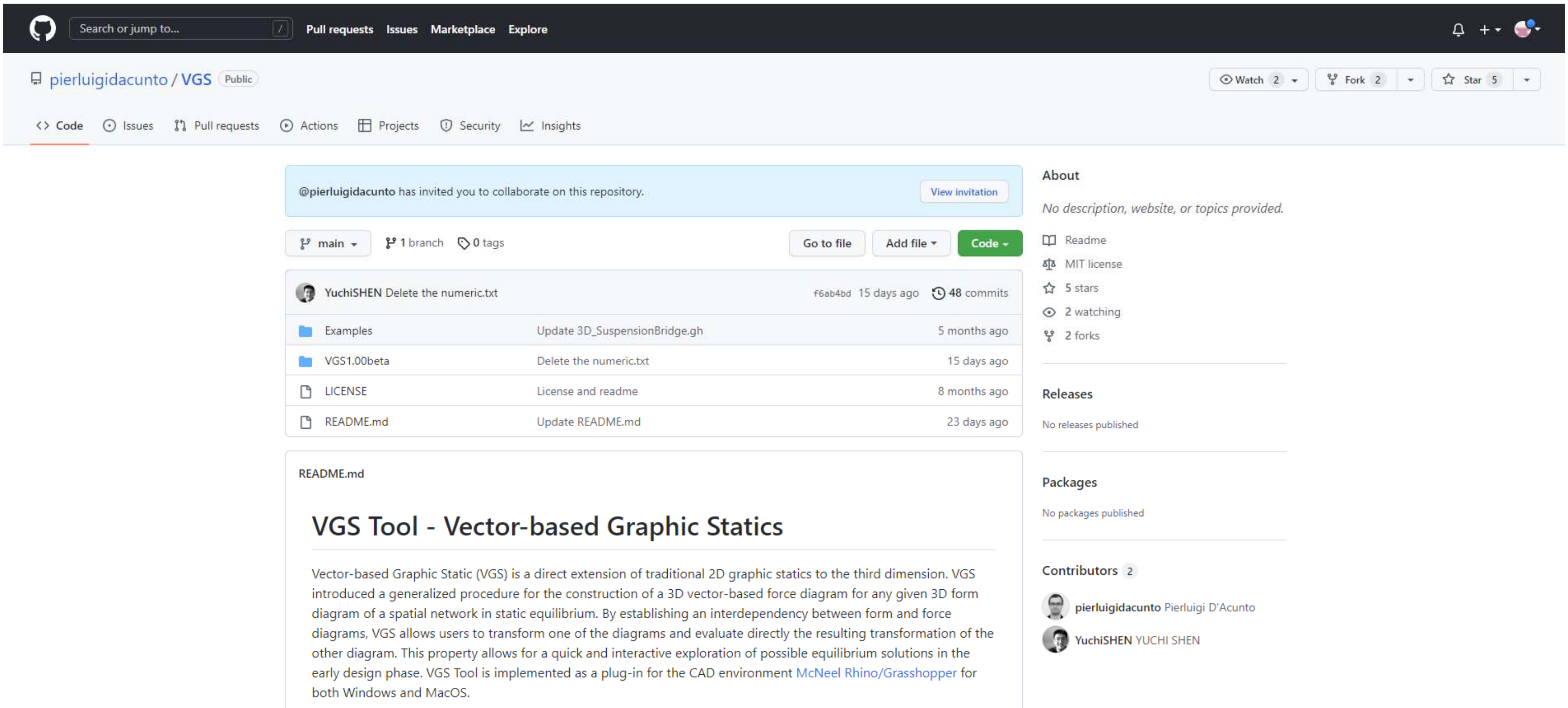


Equilibrium based design tools developed at ETH: https://compas.dev/extensions.html

Vector-based Graphic Statics (VGS)



Interactive modification of form and force diagram with VGS

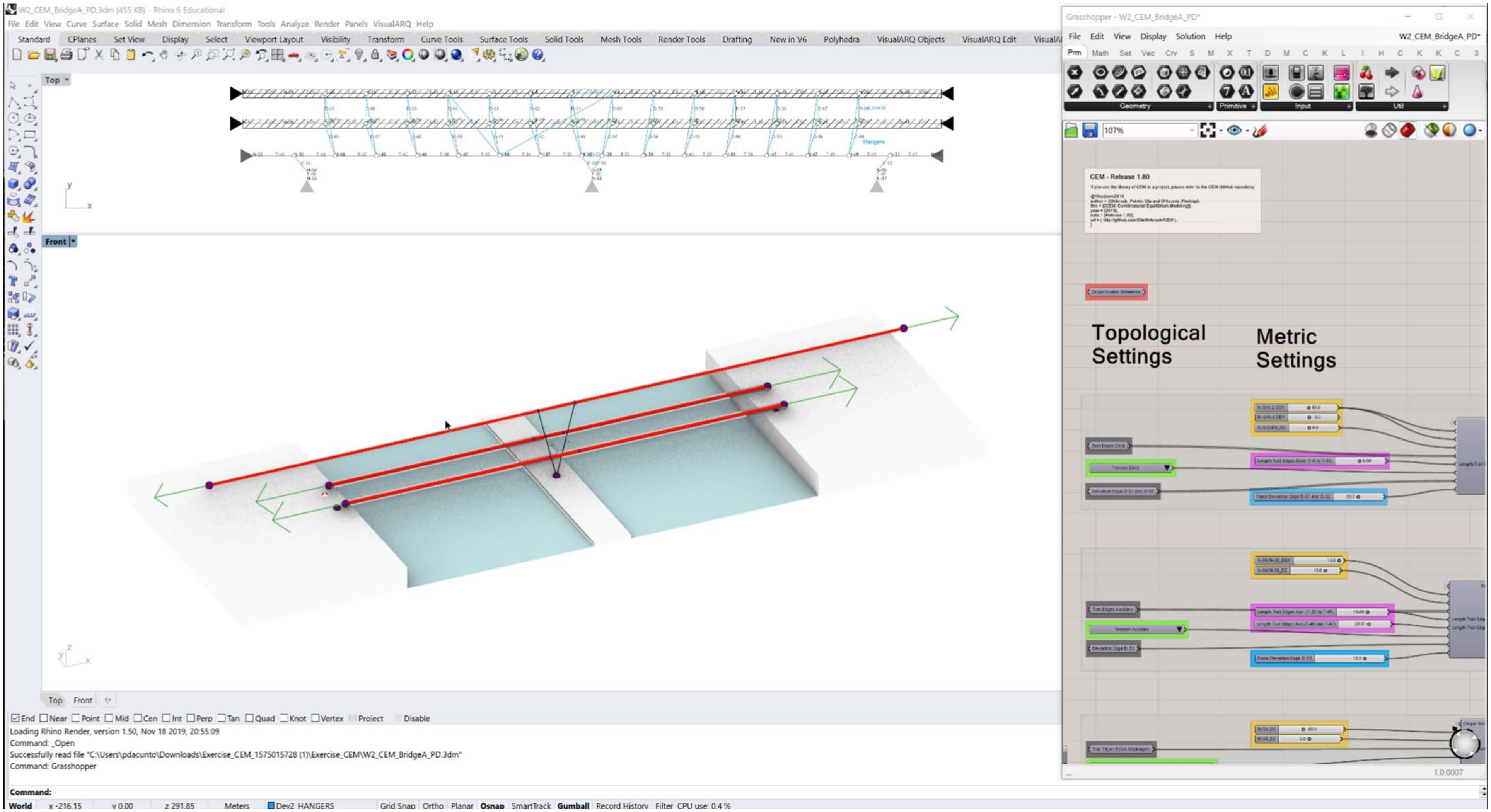


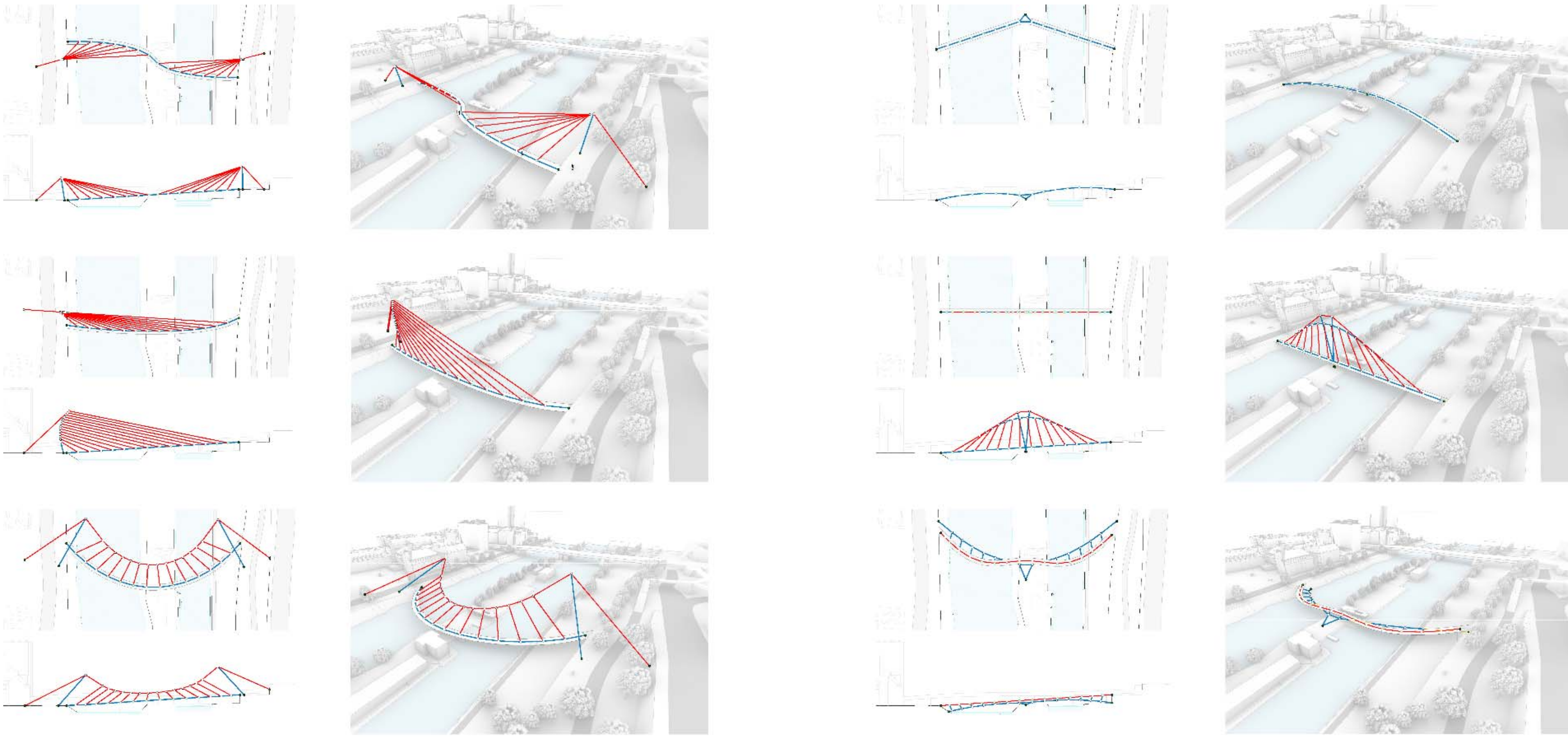
https://www.youtube.com/watch?v=9_3iyEHmEy0&t=882s

https://github.com/pierluigidacunto/VGS

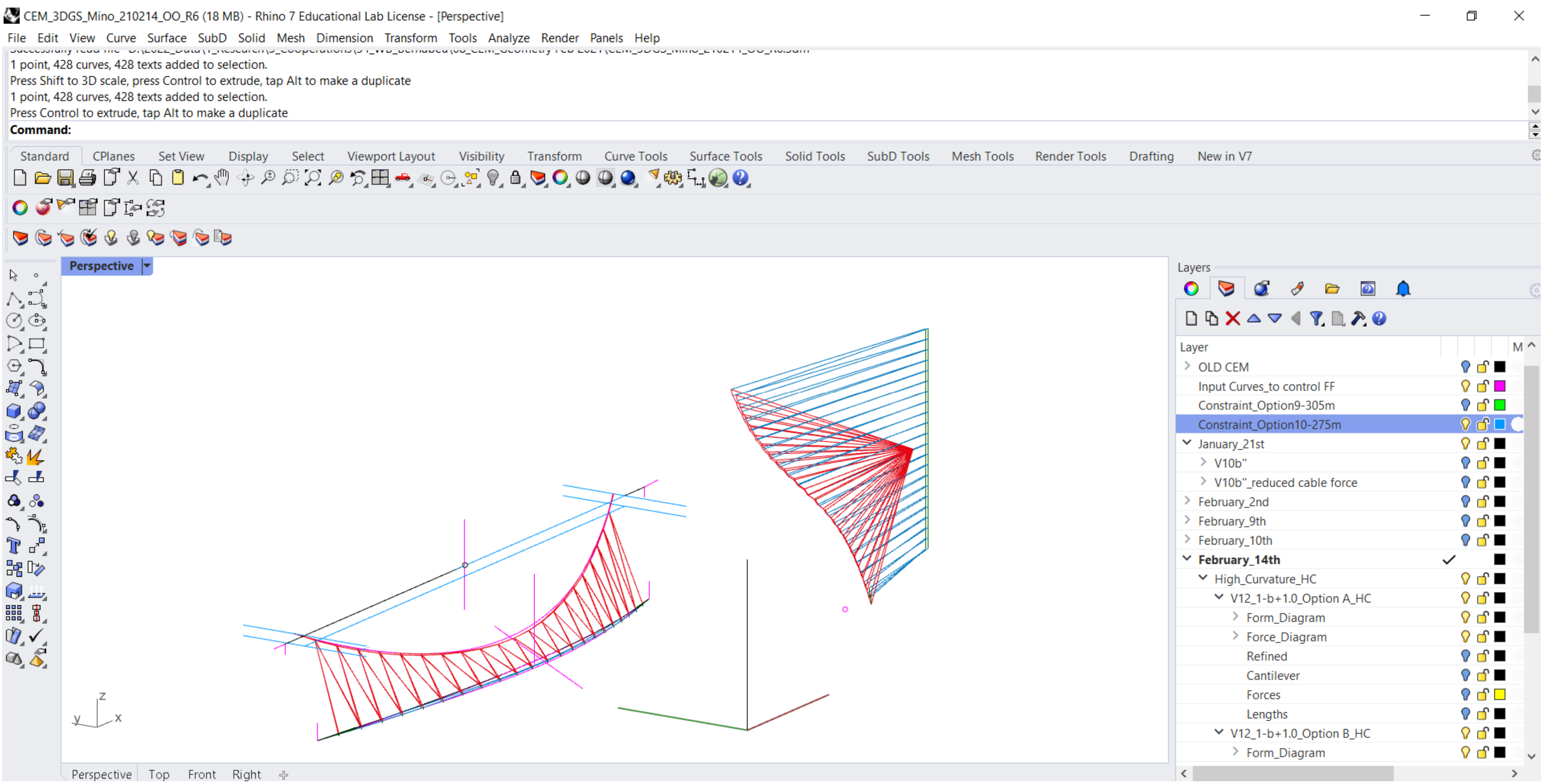
Combinatorial Equilibrium Modelling

(CEM)


Topological Settings
Metric Settings
CEM - Release 1.80



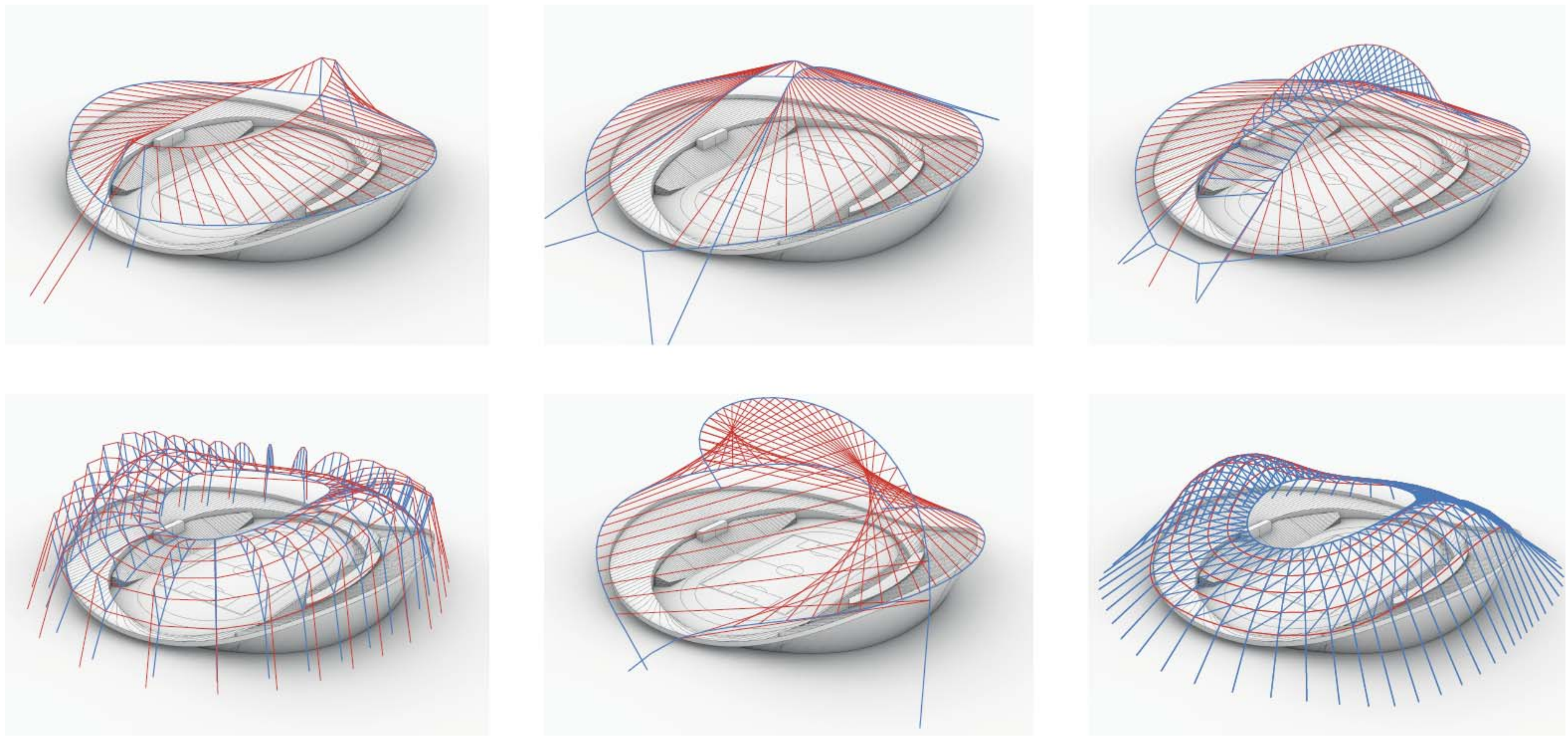
Bridge design with CEM



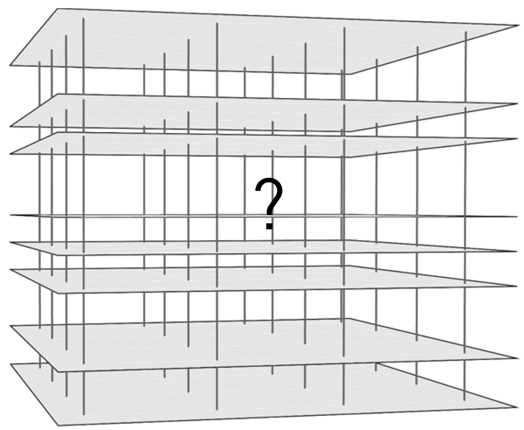
Bridge design with CEM; Goián-Vila Nova footbridge over the Miño River, Spain-Portugal with Bernabeu Ingenierios

Bridge design with CEM; Goián-Vila Nova footbridge over the Miño River, Spain-Portugal with Bernabeu Ingenierios

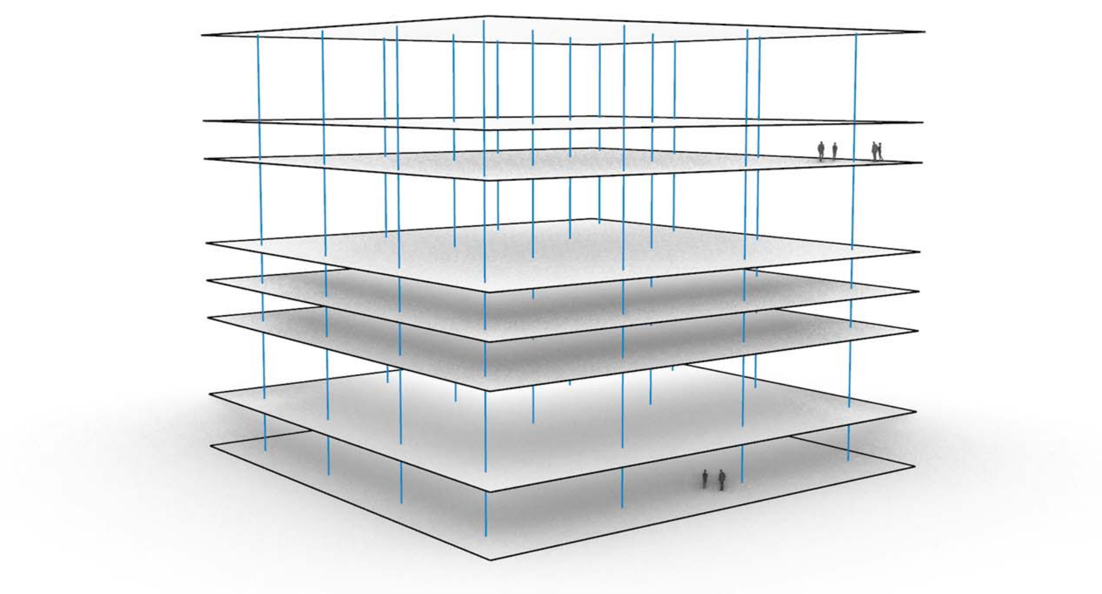
Bridge design with CEM; Goián-Vila Nova footbridge over the Miño River, Spain-Portugal with Bernabeu Ingenierios



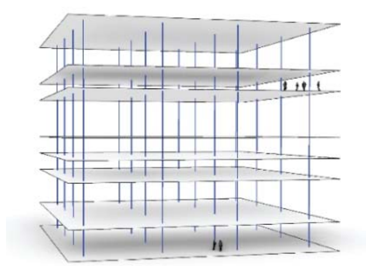
Stadium roof design with CEM

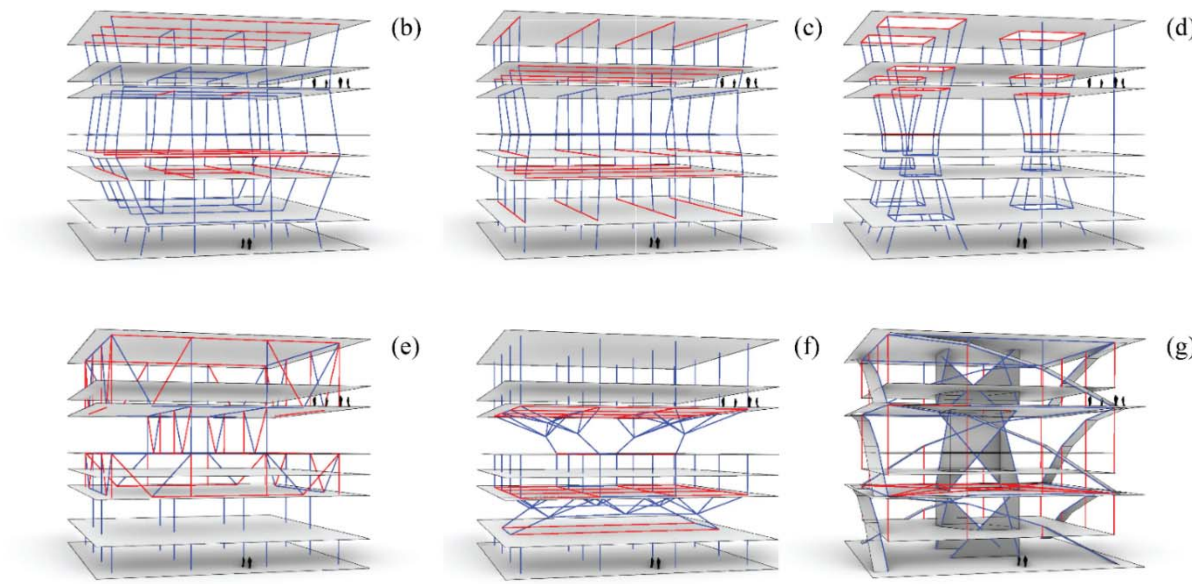


Building design with CEM

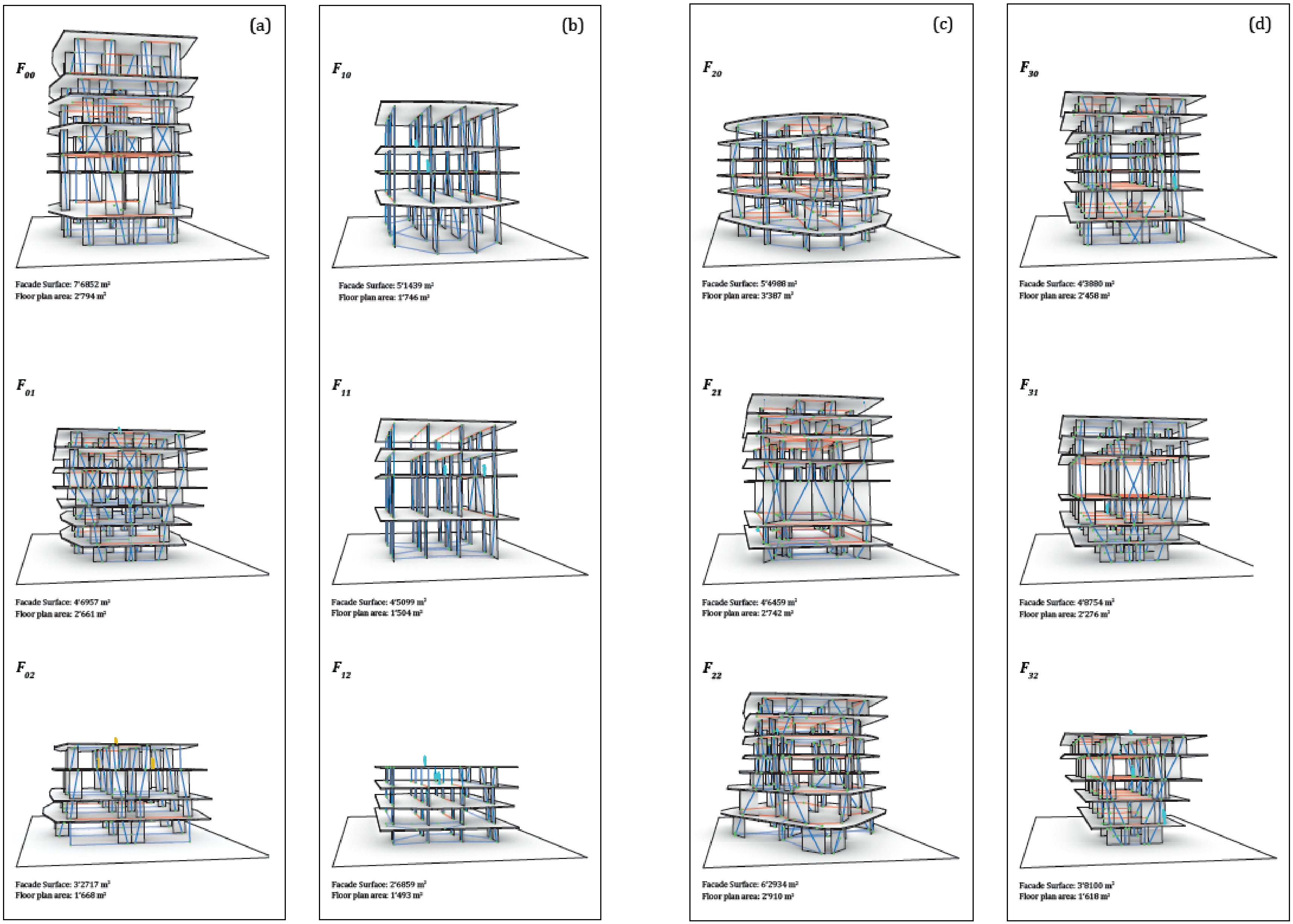


Building design with CEM





Building design with CEM

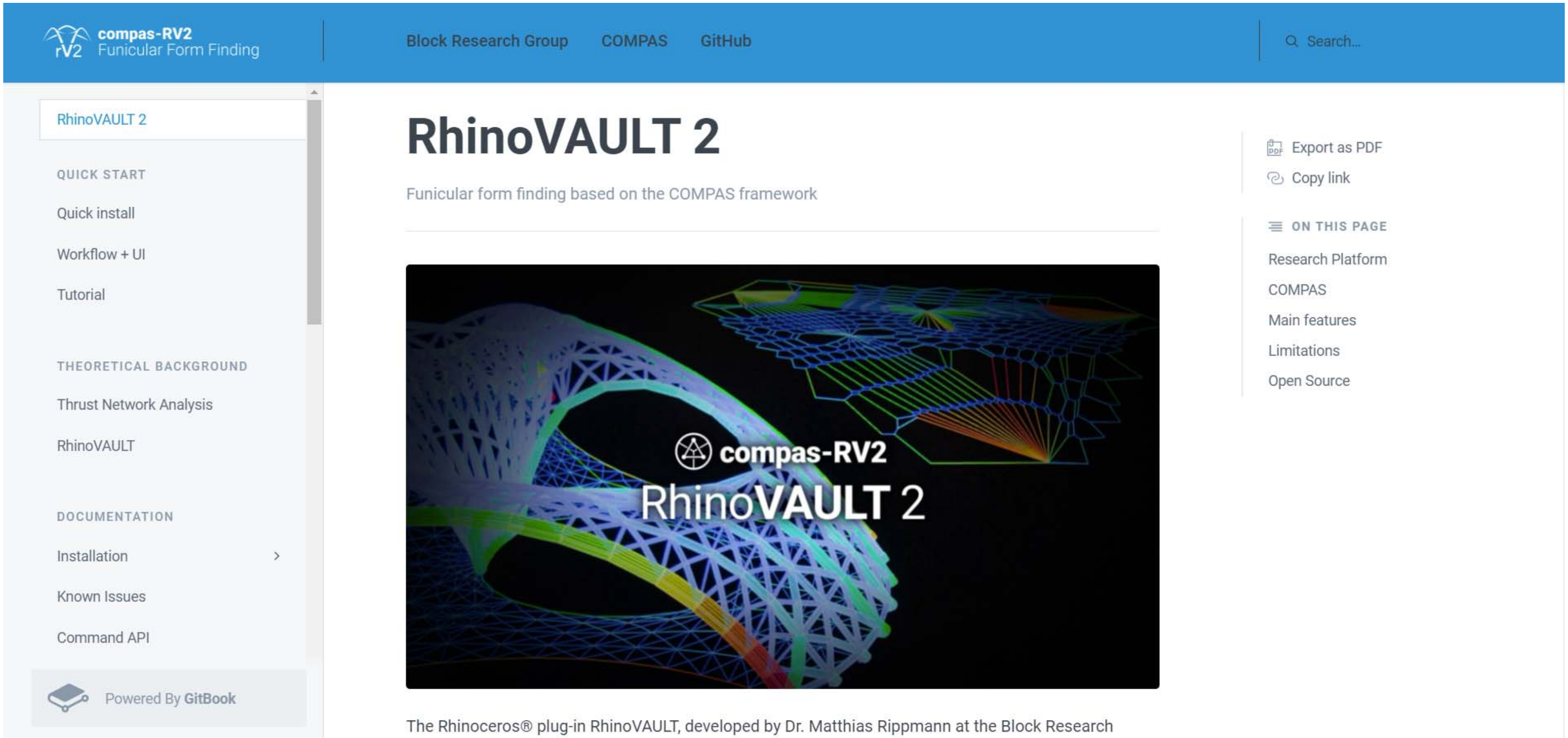


Infinite valid equilibrium options

https://github.com/computational-structural-design/CEM

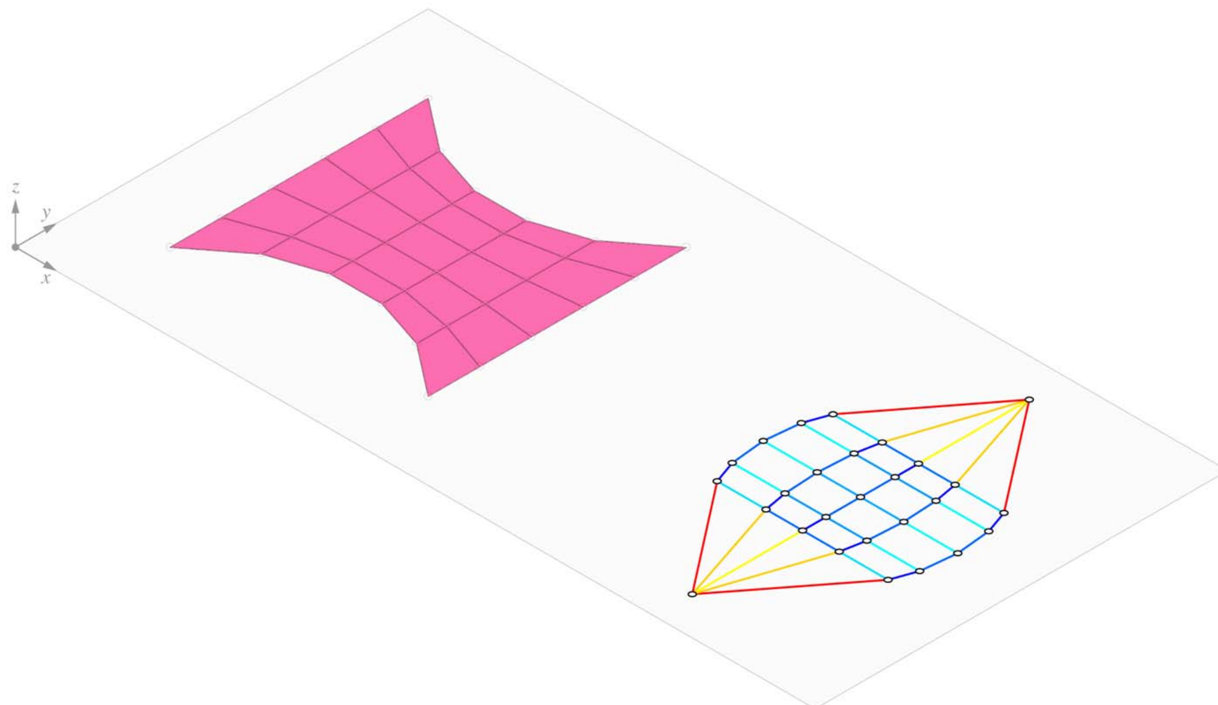
https://arpastrana.github.io/compas_cem/latest/index.html

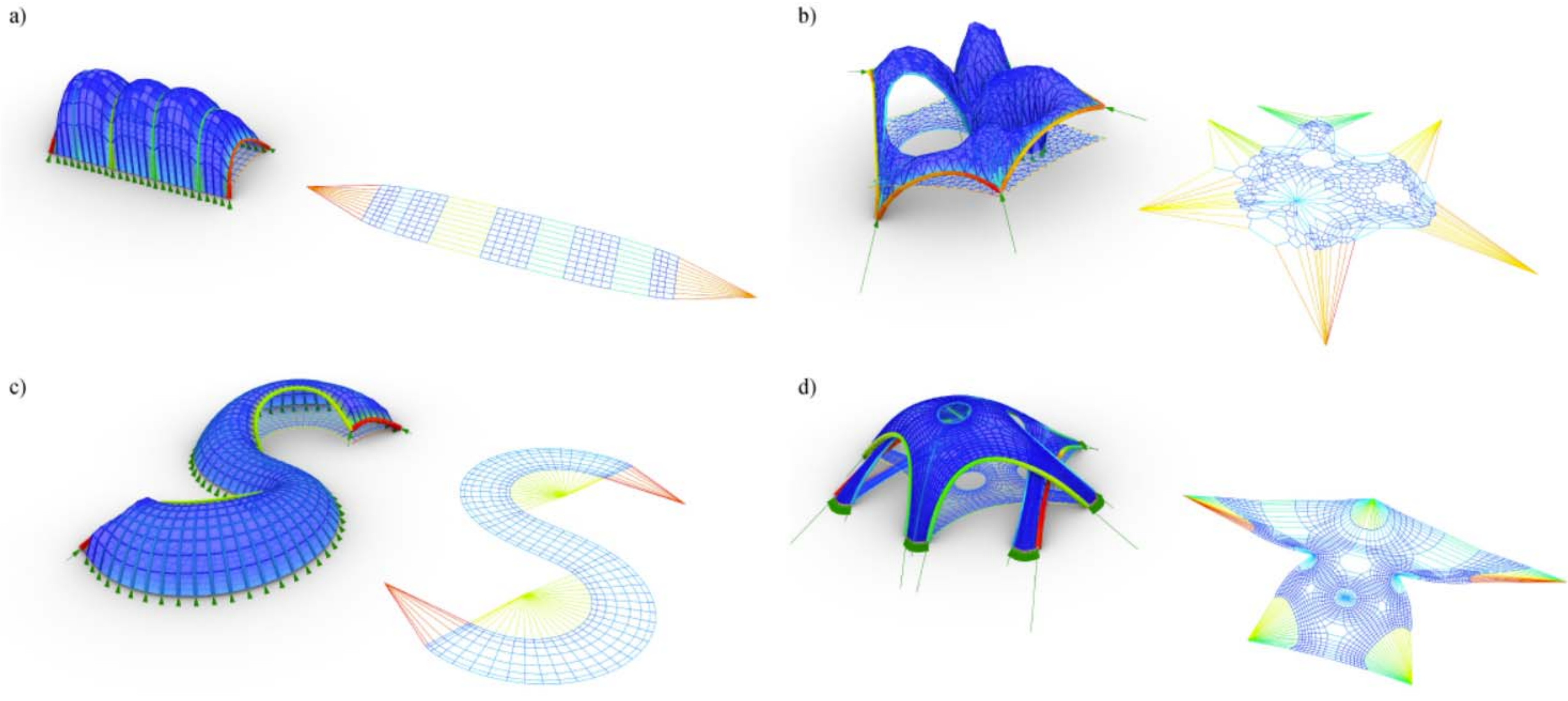
Rhino Vault 2



https://www.youtube.com/watch?v=k6vKHs5YinI

https://blockresearchgroup.gitbook.io/rv2/


z
y
x



https://blockresearchgroup.gitbook.io/rv2/

https://blockresearchgroup.gitbook.io/rv2/

Big Picture